The Notebooks
of
Leonardo Da Vinci

Other books by Edward MacCurdy

THE MIND OF LEONARDO DA VINCI

LEONARDO DA VINCI: THE ARTIST

SELF—PORTRAIT
Royal Library, Turin

THE NOTEBOOKS

OF

LEONARDO DA VINCI

Arranged, rendered into English
and Introduced
by

EDWARD MacCURDY

Volume I

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to
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King George the Sixth

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My special thanks are also due to the Librarian of the Royal Library for his kindness in allowing me to select as many illustrations as I desired from the incomparable collection of Leonardo's drawings at Windsor. It is largely as a result of this if my plates as well as my text afford some index to the almost infinite variety of Leonardo's interests. I am also much indebted to the authorities of the Prints and Drawings Department of the British Museum, for allowing me similar facilities. And my thanks are due to the staff of the London Library for many acts of courtesy extending over a number of years, to Mr. A. C. Fifield and to the preparer of the index, Mr. John Crow, both of whom have read my proofs and made many helpful suggestions.

INTRODUCTORY NOTE

1517, 10 October.

In one of the outlying parts [of Amboise] Monsignor and the rest of us went to see Messer Lunardo Vinci the Florentine. . . . This gentleman has written of anatomy with such detail, showing by illustrations the limbs, muscles, nerves, veins, ligaments, intestines and whatever else there is to discuss in the bodies of men and women, in a way that has never yet been done by anyone else. All this we have seen with our own eyes; and he said that he had dissected more than thirty bodies, both of men and women, of all ages. He has also written of the nature of water, of divers machines and of other matters, which he has set down in an infinite number of volumes all in the vulgar tongue, which if they should be published will be profitable and very enjoyable.

(Extract from *The Journey of Cardinal Luis of Aragon through Germany, the Netherlands, France and Northern Italy*, 1517-1518, written by Antonio de Beatis. Edited by Ludwig Pastor and published at Freiburg im Breisgau, 1905.)

PREFACE

I

In the year nineteen hundred and six in the audacity of youth I ventured to apply a comprehensive title to what was in reality a comparatively small selection from the contents of *Leonardo da Vinci's Notebooks.*[1] I have now attempted to redeem the promise of my title in some degree of completeness. More than half a century ago, when the work of transcription of the Leonardo manuscripts was first commenced, a controversy arose among scholars as to whether the best method of publication was by individual manuscripts or collectively with some attempt at classification. Time has a way of proving most controversies vain, and in this instance it has shown the essential rightness of the position of both disputants. The publication of the transcripts of the original manuscripts, with facsimiles, has served as the foundation of all subsequent study. Some classification of the material, however, has been found to be necessary on account of the extraordinary diversity of the subjects treated of in the same manuscript, in the majority of cases. Leonardo himself admitted as much in a prefatory note to the manuscript now in the British Museum (Arundel 263), and the action of Pompeo Leoni in compiling the Codice Atlantico out of other manuscripts by the use of scissors and paste has only made confusion worse confounded. I have therefore arranged the subject-matter under various main headings, but beyond this I have made no change of order, the passages in each section appearing in the same sequence as in the manuscripts, those of Milan coming first followed by those in Paris, London and Windsor. In the few cases, however, in which the whole or substantially the whole of a manuscript falls within the same section I have given it priority, e.g. in 'Anatomy', 'Flight', 'Painting', and 'Optics'.

About a dozen pictures are all that can be attributed to Leonardo with any degree of certitude or even of probability, and the witness of contemporary record, however credulously interpreted, does not do

[1] *Leonardo da Vinci's Notebooks*, Edward MacCurdy, M.A., crown 8vo, 14 illustrations, pp. xiv, 289. London: Duckworth & Co., 1906.

more than double or treble the number. How he disposed of his time would be an enigma but for the existence of the vast collection of drawings, and particularly of the notebooks. These number upwards of five thousand pages, the contents of which I have attempted to classify under some fifty headings. The classification is, as I know, rough and imperfect, this the wellnigh infinite variety of the contents having rendered almost inevitable. For, of this man who did a few works of art most divinely well, it may be said that he took all knowledge as his province, and that in his individual achievement he symbolizes the diversity of an epoch as fully as can be said of any man at any period in the world's history. To one who has studied them intermittently for more than a quarter of a century these manuscripts — the product of how many thousand hours of intellectual activity! — are the records of the working of the mightiest machine perhaps that has ever been a human brain: fragments of a larger purpose, charted, defined, explored, but never fulfilled, of which the treatises containing the sum of his researches in anatomy, physiology and geology form component parts, fragments of a vast encyclopaedia of human knowledge.

What thinker has ever possessed the cosmic vision so insistently? He sought to establish the essential unity of structure of all living things, the earth an organism with veins and arteries, the body of a man a type of that of the world. The perceptions of his brain are hardly if at all fettered by bondage of time and place. At rare times, however, the personal note supervenes and moods of exultation or depression flash out their meaning in a phrase. The mood of the seer finds expression in fable or allegory, or in the series of 'the Prophecies', revealing the depth of his mordant humour and his power of analysis of the motives which guide human conduct, or in speculation as to results that would follow possible extension of man's power — in which time has confirmed his prescience and his foreboding.

The manuscripts are a wellnigh inexhaustible quarry in which the student of every phase of Leonardo's mental activity will find material. They are of peculiar value for the biographer, both in their revelation of personality and in the manner in which they react on contemporary record. Thus they tend to confirm Vasari in his more picturesque statements. He has told how Leonardo when he passed the places where birds were sold would often take them from their cages, pay the price demanded, and restore their liberty by letting them fly

into the air. 'The goldfinch', wrote Leonardo, 'will carry spurge to its little ones imprisoned in a cage — death rather than loss of liberty.' The purport of the note becomes clear from the fact that certain varieties of the spurge form a violent poison. His account of how Leonardo collected lizards, hedgehogs, newts, serpents and all sorts of strange creatures, and from these constructed the head of a hideous monster, when in his youth he received a commission to paint something on a shield which should cause terror to the beholder, is directly confirmed by the painter's own precept, 'how to make an imaginary animal appear real'; the method being that each part should have a basis of reality, thus the body of a serpent, head of a mastiff or setter, eyes of cat, ears of porcupine, nose of greyhound, eyebrows of lion, temples of an old cock and neck of turtle. So also with reference to Leonardo's activities as master of pageant at the Court of Milan, the automatic lion which according to Vasari formed part of the pageant on the occasion of the entry of the French King, that advanced a few steps and opened its breast to show it filled with lilies, is drawn in different positions on a page of the Anatomy MSS. at Windsor.

The letters and fragments of letters are also of primary importance for the biographer. They sound the whole gamut of sensations from the proud confidence of the first letter to Ludovic and that to the Commissioners of the Cathedral of Piacenza, through the terse appeals of the later days in Milan when 'the horse' was ready for the casting and foreign subsidies had exhausted the Treasury, to those written in the depression of the Roman period, when his hopes of employment had been frustrated and he had been denounced to the Pope for his practice of anatomy, while his nerves were reacting helplessly to the misbehaviour of an apprentice.

Of the real ultimate value of the results of Leonardo's various scientific researches and investigations I have no title to attempt to speak. They can be judged only by specialists, and when a section is thus passed under review the result from the time of Dr. William Hunter onwards has been to confirm the impression of their great worth, establishing him as a thinker of very exact powers of analysis as well as a fertile investigator whose work shows a firm grasp of the principles of experimental science. For example, among the anatomical investigations which find record in the Windsor Manuscripts is that of the spinal cord and intestines of the frog. 'The frog', he says, 'retains life for some

hours when the head, the heart, and all the intestines have been taken away. And if you prick the said cord it instantly twitches and dies' (Quaderni V 21 r.). On the reverse of the same sheet is written: 'the frog instantly dies when the spinal cord is pierced; and previous to this it lived without head, without heart, or any bowels or intestines or skin; and here therefore it would seem lies the foundation of movement and life.'

The originality of his methods of anatomical investigation is illustrated by the details he gives of the making of wax casts in order to discover the true form of the ventricles of the brain:

> 'Make two air holes in the horns of the great ventricles and insert melted wax by means of a syringe, making a hole in the ventricle of the memoria, and through this hole fill the three ventricles of the brain; and afterwards when the wax has set take away the brain and you will see the shape of the three ventricles exactly. But first insert thin tubes in the air holes in order that the air which is in these ventricles may escape and so make room for the wax which enters into the ventricles' (Quaderni V 7 r.).

Leonardo, as the learned editors of the Quaderni d'Anatomia inform us, was the first to make casts of the cerebral ventricles, and several hundred years elapsed before the idea occurred to any other anatomist.

It is on the fringe of this uncharted knowledge that the gift of expression often haunts and tantalizes by its beauty.

'Every weight tends to fall towards the centre by the shortest way' (C 28 v.) is the kernel of Newton's law of gravitation. 'The earth is moved from its position by the weight of a tiny bird resting upon it. The surface of the sphere of the water is moved by a tiny drop of water falling upon it' (B.M. 19 r.). Is this also the language of mechanics?

In the section of his treatise on 'Painting', in which he institutes comparison between painting and the other arts, he has no divided allegiance; but, in 'the Prophecies', he has expressed his sense of the potentialities of literature, although somewhat enigmatically: 'Feathers shall raise men even as they do birds, towards heaven; that is by letters written with their quills.'

Although disclaiming for himself all title to the rank of literary artist he displays a remarkable power of lucid expression, so that his language seems exactly to mirror his thought and his phrases arrest by their simplicity. This literary quality pervades his humour, which is on occasion terse and trenchant, e.g. 'that venerable snail the sun'; 'Man

has great power of speech but the greater part thereof is empty and deceitful. The animals have little but that little is useful and true; and better is a small and certain thing than a great falsehood'. The latter sentence might fitly serve as proem to the 'A Bestiary' in Manuscript H, where it is stated of the great elephant that he has by nature qualities which rarely occur among men, namely probity, prudence, and the sense of justice and of religious observance. There is perhaps something of the same mood to be discerned in the instruction that the leather bags, intended to prevent an aviator from doing himself any harm if he chance to fall a height of six braccia on water or on land, should be tied after the fashion of the beads of a rosary; or when after referring to the damage caused to great things by the firing of a cannon he speaks of the spiders' webs being all destroyed. So also where under the rubric 'Of local movement of flexible dry things' he discusses the movement of dust when a table is struck — of the dust which is separated into various hillocks descending from the hypotenuse of these hillocks, entering beneath their base and raising itself round the axis of the point of the hillock, and so moving as to seem a right-angled triangle. One finds one's self wondering when if ever the table was dusted, and reflecting as to how much his powers of observation would have been cramped by matrimony.

I have not considered it necessary to transcribe the numerous pages of Latin declensions and conjugations or the various portions of a Latin-Italian glossary which are to be found in Manuscript H of the 'Institut'. It has been suggested that they were compiled for the instruction of Maximilian and Francesco Sforza, who were born in January 1493 and February 1495, and whose features are familiar as they kneel in chubby complacency in the Zenale altar-piece in the Brera, and the elder of whom is the boy seen sitting reading Cicero in the fascinating fresco by a Milanese painter now in the Wallace Collection. It is somewhat difficult to fit Leonardo into the part of a private tutor to the Sforza princes although he performed various functions at the court, but it is quite possible that these lists, although as usual they are in 'left-handed writing', were compiled for the purpose of imparting information. The fact that the allegories about animals, which are for the most part a compilation from Pliny and medieval bestiaries, are also found in Manuscript H suggests the possibility that if the Latin grammar and glossary were written for the instruction of the Sforza princes,

Leonardo's book of beasts may have been put together for their edification as a sort of antidote, so that the acerbities of the Latin conjugations might be varied by such rare and refreshing fruit as the story of the amphisbaena — a four-footed beast that resembled the Pushmipullyou of Hugh Lofting's Dolittle books in having a head at each end, both of which, however, discharged poison, unlike those of the modern story. Leonardo's imagination is seen perhaps in completest freedom in the fragment of a fantastic tale in the form of letters, in the Codice Atlantico. The giant of such stature that when he shook his head he dislodged showers of men who were clinging to the hairs, is a fantasy curiously suggestive of the actions of Gulliver in Lilliput.

The problem of the interpretation of the letters purporting to be written from Armenia has been a vexed question ever since Dr. Jean Paul Richter made their existence known. The evidence, I think, tends to confirm the view that they are a record of fact and that Leonardo was for a time in the East, nor as it seems to me is this interpretation rendered untenable as Dr. Verga would seem to suggest, by the circumstance of Leonardo having used the classical nomenclature of Ptolemy in these letters. The references to books which occur in Leonardo's manuscripts show that he was in the habit of studying all classical and medieval authorities obtainable on the subjects in which he was interested. Ptolemy was one of the chief sources from which he gratified his curiosity as to the distant and dimly recorded places and peoples of the earth. Pliny, Strabo, and even Sir John Mandeville also figure in the category. The system of nomenclature of Ptolemy supplied the forms he must inevitably have used in expressing his first conceptions of distant places. The same consideration must certainly have operated in the minds of many contemporary travellers. Geography was one of the sciences in which the knowledge of classical literature may be said to have lain like a dead hand. Leonardo's debt to Ptolemy was great. In a passage in his treatise on anatomy in which he described how his system of dissection of the various parts of man is to be so co-ordinated that the result may reveal the structure or mechanism of the whole body, he pays a tribute to Ptolemy as a master of synthetic arrangement whom he is proud to follow: 'therefore there shall be revealed to you here in fifteen entire figures the cosmography of the "minor mondo" [the Microcosmos or 'lesser world'] in the same order as was used by Ptolemy before me in his cosmography'. May not his debt to Ptolemy

have been much the same in the one case as in the other — in the one the arrangement, in the other the nomenclature, and perhaps the first interest in places?

The manuscripts are the repository of much practical wisdom designed to sweeten the intercourse of life and revealing itself in divers unexpected ways. A social reformer might profitably stand upon the precept: 'Let the street be as wide as the universal height of the houses'. The evils of absentee landlordism and those resulting from the amassing of huge estates — 'field laid unto field, that they may be placed alone in the midst of the earth' — are alike exorcized in the sentence, 'Happy is that estate which is seen by the eye of its lord'. Riches had lost some of their chief lures for the man who could write thus: 'Small rooms or dwellings set the mind in the right path, large ones cause it to go astray'; and, 'Wine is good but water is preferable at table'.

The golden mean in all things — failing this, renunciation. 'Entbehren sollst du, sollst entbehren.' 'Neither promise yourself things nor do things', he wrote, 'if you see that when deprived of them they will cause you material suffering'. The sentence serves to recall a remark once uttered by Dr. Jowett on the subject of smoking: 'Do not set up for yourself any new necessities'.

This practical sense is always perceptible when he is discussing the subject of art. In his 'Botany for Painters' he pauses in the act of defining the laws of branch structure to address the painter who, as he recognizes, is bound to be unacquainted with these laws, and to assure him that he may escape the censure of those who have studied them if he is zealous to represent everything according to Nature. So also in discussing the flight of birds (C.A. 214 r. a) he turns for parallel to the movement of the fish's tail; and this, he says, may be proved with a pair of oars. And in stating the variation in a bird's weight as it spreads itself out or draws itself together (E 43 v.) he adds, 'and the butterflies make experiments of this in their descents'. At times, however, the operation of this practical sense is obscured by the insistence upon primary laws: e.g. 'In order to give the exact science of the movement of the birds in the air it is necessary first to give the science of the winds, and this we shall prove by means of the movements of the water. This science is in itself capable of being received by the senses: it will serve as a ladder to arrive at the knowledge of flying things in the air and the wind' (E 54 r.).

Of the closeness and exactness of his power of observation certain of

the anatomical drawings afford example, equally with the studies for pictures. The lines seem to have the spontaneity and inevitability of life itself. The same power translated is visible in his descriptions of Nature in her changeful moods. These have something of the effect of studies taken with a camera at close range. As when for example he speaks of the waves made by the wind in May running over the cornfields without the ears of corn changing their place; of reeds scarcely visible in the light but standing out well between the light and the shade (L 87 r.); of waves which intersect after the manner of the scales of a fir cone, reflecting the image of the sun with the greatest splendour because the radiance of so many reflections is blended together (B.M. 25 r.); of water in impact with a larger fall turning like the wheel of a mill (F 81 r.). A statement in the Leicester Manuscript (13 r.) as to the surface of tiny shadowed waves shaping itself in lines that meet in an angle, as though formed by the sand, this being proof of its shallowness, might serve as an exact description of the treatment of waves in Botticelli's 'Birth of Venus', as also in certain of his illustrations to Dante. Botticelli, who frequented Verrocchio's studio when Leonardo was there as a pupil, is the only one of his Florentine contemporaries whose practice was cited by him in his writings on art. While thus on the one hand his teaching might serve to interpret the practice of Botticelli, it bridges the wellnigh bottomless gulf in which the votaries of classicism forgather, and anticipates the freedom of composition and subtilty of atmospheric effects of the period of naturalism. His precept that the mind should seek stimulation to various inventions from the spectacle of the blend of different stains on a wall, postulates utmost liberty in arrangement. The most delicate evanescent effects of Anton Mauve, or of Courbet at the time when he painted his 'Duck Shooter', are brought before us by such a sentence as the following: 'No opaque body is without shadow or light except where there is a mist lying over the ground when it is covered with snow, or it will be the same when it snows in the country' (Quaderni II 6 r.).

Similarly the spirit of Whistler's creations is evoked in the directions under the rubric, 'How to represent white figures' (MS. 2038 Bib. Nat. 20 r.); and Turner's most characteristic effects are recalled by the ethereal simplicity and directness of Leonardo's description of the phenomena of sunrise:

'At the first hour of the day the atmosphere in the south near to the

horizon has a dim haze of rose-flushed clouds; towards the west it grows darker, and towards the east the damp vapour of the horizon shows brighter than the actual horizon itself, and the white of the houses in the east is scarcely to be discerned; while in the south, the farther distant they are, the more they assume a dark rose-flushed hue, and even more so in the west; and with the shadows it is the contrary, for these disappear before the white' (C.A. 176 r. b).

Who having witnessed the sequence of the effects of sunrise from the angle of observation afforded by a hilltop, can doubt Leonardo's description to be a record of what he had actually seen?

'Pre-imagining — the imagining of things that are to be. Post-imagining — the imagining of things that are past.' So in a passage in the Windsor Manuscripts Leonardo defines with singular felicity two fields of thought over which his spirit ranged with a freedom only limited by the necessity of interpreting natural phenomena. The Leicester Manuscript contains the sum of his researches in the natural history of the earth; in the records that time has written in the rocks and the high deposits of the mountain ranges, of the period when as he says 'above the plains of Italy where now birds fly in flocks fishes were wont to wander in large shoals'. 'Sufficient for us', he states, 'is the testimony of things produced in the salt waters and now found again in the high mountains far from the seas.' Elsewhere in the same manuscript he refers to the discovery of a prehistoric ship found during the digging of a well on the country estate of one of Ludovic Sforza's retinue, and the decision taken to change the position of the well in order to leave it intact. In a passage in the Arundel Manuscript he apostrophizes as a once-living instrument of constructive nature the form of a great fish whose bones despoiled and bare, as it lies in a hollow winding recess of the hills of Lombardy, are become as an armour and support to the mountain that lies above it. The lines seem charged with just such sensations as must have animated that first scientist in the Dordogne whom a fortunate chance led to enter the caves of Les Eyzies.

But it is in the realm of pre-imagining, 'the imagining of things that are to be', that the manuscripts constitute the most impressive revelation of his creative thought. That a single mind could conceive and anticipate the growth of knowledge at such divers points as the circulation of the blood, the heliocentric theory, the law of inertia, the *camera obscura*, is only to be believed because the evidence for it exists.

In the fragment of a torn letter written apparently to Ludovic Sforza during the embarrassed later years of his rule in Milan, Leonardo reveals how disastrous from the standpoint of the artist were the exigencies of the time. The same may also be said with regard to the conditions which prevailed over Europe during a considerable period of the Great War: the arts put to silence and altar-piece and fresco hidden away in bomb-proof shelters or protected with sand-bags. To the completeness of this silence, however, as affecting the great names in art, that of Leonardo formed a unique exception. In war as in peace the course of events demonstrated that as Sirèn has said, 'no one can be indifferent to Leonardo'. All the most characteristic developments of the Great War, those which distinguish it from all in the long roll of its predecessors — the use of the bombing aeroplane, the use of poison gas, the tank and the submarine — all afford examples of his prescience. He foretold the construction of each, not with the enigmatic utterance of the seer, but with such precision of scientific and mechanical detail as would be natural in one who held, as did Leonardo, the office of military engineer in the Romagna under Caesar Borgia during the brief tenure of his power, and had offered his services in a similar capacity to Ludovic Sforza. It may seem something of an enigma that such activities should have emanated from the brain of one who has stigmatized warfare as 'bestialissima pazzia' (most bestial madness). The clue to its solution is to be found, however, in a passage in one of the Leonardo Manuscripts in the Bibliothèque Nationale (MS. 2037, 10 r.) in which he refers to the difference between offensive and defensive warfare, and emphasizes the necessity of preparation for the one as a safeguard of all that life holds most dear: 'When besieged by ambitious tyrants I find a means of offence and defence in order to preserve the chief gift of Nature, which is liberty', and so he goes on to speak first of the position of the walls, and then of how people may maintain their good and just lords.

He envisaged the scientific possibilities of the use of poison gas in naval warfare, gave a formula for its composition and described how a mask might be made to act as a preventive. It is impossible lightly to assume that Leonardo, who has written: 'It is an infinitely atrocious thing to take away the life of a man', would have regarded the use of poison gas against the civil population as permissible under any circumstances.

The prototype of the tank or armoured car appears in one of

Leonardo's drawings in the British Museum. He has thus foreshadowed its use in breaking the line: 'these take the place of the elephants. One may tilt with them. One may hold bellows in them to spread terror among the horses of the enemy, and one may put carabiniers in them to break up every company' (B 83 v.).

In this as in his attempts to construct a machine for flight, he was hampered by the lack of knowledge of a suitable motive power for propelling such a machine. He studied the laws of flight and the conditions under which it existed in Nature with inexhaustible zeal, and his scientific deductions from these go far to create the type of the modern aeroplane. He thought of flight as man's natural entry into the deferred inheritance of the air, and did not, apparently, foresee that such was man's nature that his wings would inevitably become the wings of war. Had he envisaged the extension of man's power as enabling him to rain death from the skies his attitude might conceivably have been that of the artist in Johnson's *Rasselas*, of whom it is related that having mastered the art of flying by the invention of wings on the model of those of the bat he refused to divulge his secret. 'If men were all virtuous', he said, 'I should with great alacrity teach them all to fly. But what would be the security of the good, if the bad could at pleasure invade them from the sky? Against an enemy sailing through the clouds neither walls nor mountains and seas could afford any security. A flight of northern savages might hover in the wind and light at once with irresistible violence upon the capital of a fruitful region that was rolling beneath them. Even this [the Amharic] valley the retreat of princes . . . might be violated.'

The conjecture that such would in fact have been Leonardo's attitude is further strengthened by the nature of his remarks, on the subject of the unrestricted use of the submarine. The passage, in the Leicester Manuscript (22 v.), is as follows:

'How by an appliance many are able to remain for some time under water. How and why I do not describe my method of remaining under water for as long a time as I can remain without food; and this I do not publish or divulge, on account of the evil nature of men, who would practise assassinations at the bottom of the seas by breaking the ships in their lowest parts and sinking them together with the crews who are in them.'

'To preserve the chief gift of Nature which is liberty' — this if not the motive underlying all his study of mechanisms of warfare was un-

doubtedly a controlling factor; for in the world as he envisaged it there is sovereign liberty for the individual to think and devise.

As the long labour of preparation of this edition of Leonardo's writings draws to an end, a letter comes to me from the United States telling me of the fact of the Faculty of Princeton University having drawn up a list of ten names of men of all time who have done most to advance human knowledge. The names are: Socrates, Plato, Aristotle, Galileo, Leonardo, Pasteur, Shakespeare, Newton, Darwin and Einstein. No such list is ever likely to win general agreement, for the lack of a common standard of values. It may at any rate be claimed for this one that each name is cut deep in the rock of achievement. In thought of some of the names the strange prescience which has caused Leonardo to be styled 'the forerunner' recurs inevitably to the mind. As, independently of the researches of Galileo, he wrote 'the sun does not move', so he enunciated the root principle of Newton's law of gravitation in the words: 'every weight tends to fall towards the centre by the shortest way'; so also in several passages the nature of which is indicated by such a sentence as the following: 'write of the quality of time as distinct from its mathematical divisions', he would seem to have been pointing along the road which in our own times has been travelled by Einstein.

Where his energy shows itself most inexhaustible is in the investigation of the working of the elemental forces, as in the sections, 'Movement and Weight' and 'Water'. As water may be seen winding in wonder-working coils through his landscape backgrounds, so with infinite zeal he set himself to study how the elements are situated one within the other, why water moves and why its motion ceases, how it rises in the air through the heat of the sun, and afterwards falls in rain: the artist's love of beauty transforming the scientist's purpose even while he is in the act of wresting from its infinite variety its underlying principles.

Certain of the results of these investigations formed that volume on 'The Nature of Water' which was one of those seen in the manor house at Cloux near Amboise, where Leonardo passed the last three years of his life, and where in October 1517 he was visited by a Cardinal of Aragon and his retinue. To the fortunate circumstance of the Cardinal's secretary Antonio de Beatis having kept a diary in which he set down particulars of the visit, we owe our knowledge of the fact that the Leonardo manuscripts there formed 'an infinite number of volumes . . . which if they should be published will be profitable and very enjoyable'.

II

The early biographers of Leonardo da Vinci cultivated the picturesque with an almost metrical licence. Their narratives, which together constitute what Pater has termed the *légende*, are as inadequate to reveal his work and personality as the fables of Vulcan's forge and the like are unsatisfying as an origin for Etna's fire. Moreover, in the different aspects which Etna has assumed to the imagination, seeming at first a caprice of the gods and a thing of rhapsody, and subsequently — as the tenor of thought changed — a field for the scientific study of the forces of Nature, there is presented a contrast no less sharply defined, and in its main features somewhat closely corresponding to that presented by the personality of Leonardo as shown in the earliest biographies and in the light of modern research. For the capricious volatile prodigy of youthful genius which the *légende* has bequeathed, the latter has substituted a figure less romantic, less alluringly inexplicable, but of even more varied and astonishing gifts. His greatness as an artist has suffered no change, but modern research has revealed the ordered continuity of effort which preceded achievement. It has made manifest how he studied the structure of the human frame, of the horse, of rocks and trees, in order the better to paint and make statues, in that his work would then be upon the things he knew, and no sinew or leaf would be conventional, but taken directly from the treasury of Nature; since the artist should be 'the son, not the grandson of Nature'.

This habit of scientific investigation in inception subsidiary to the practice of his art, so grew to dominate it as to alienate him gradually from its practice to the study of its laws, and then of those which govern all created Nature. The fruits of these studies lay hidden in manuscripts of which the contents have only become fully known within the last half century. So by a curious appositeness he is associated in each age with the predominant current of its activity. His versatility in the arts caused him to seem an embodiment of the spirit of the Renaissance. Alike as painter, sculptor, architect, engineer and musician, he aroused the wonder and admiration of his contemporaries. But to them, the studies which traversed the whole domain of Nature, prefiguring in their scope what the spirit of the Renaissance should afterwards become, were so imper-

fectly comprehended as to seem mere trifles, 'ghiribizzi', to be mentioned apologetically, if at all, as showing the wayward inconstancy of genius, and with regret on account of the time thus wasted which might have been spent on painting. Modern savants have resolved these trifles, and in so doing have estimated the value of Leonardo's discoveries and observations in the realms of exact science. They have acclaimed him as one of the greatest of savants: not in completed endeavour which of itself reached fruition, but in conjecture and prefigurement of what the progress of science has in course of centuries established. Such conjecture, moreover, was not grounded in fantasy, but was the harvest of a lifetime of study of natural phenomena, and of close analysis of their laws. Anatomist, mathematician, chemist, geologist, botanist, astronomer, geographer — the application of each of these titles is fully justified by the contents of his manuscripts at Milan, Paris, Windsor and London.

To estimate aright the value of his researches in the various domains of science would require an almost encyclopaedic width of knowledge. In respect to these Leonardo himself in his manuscripts must be accounted his own best biographer, in spite of what may appear the enigmatic brevity of some of his statements and inferences. It is not possible to claim for him originality in discovery in all the points wherein his researches anticipated principles which were subsequently established. So incomplete is the record of the intellectual life of Milan under the Sforzas, which has survived the storms of invasion that subsequently broke upon the city, as to cause positive statement on this point to be wellnigh impossible; something, however, should be allowed for the results of his intercourse with those who were occupied in the same fields of research. We are told that at a later period he was the friend of Marc Antonio della Torre who held the Chair of Anatomy in the University of Pavia, and that they mutually assisted each other's studies. He was also the friend of Fra Luca Pacioli, the mathematician, and drew the diagrams for his *De Divina Proportione*, and the two were companions for some time in the autumn and winter of 1499 after leaving Milan together at the time of the French invasion. Numerous references and notes which occur throughout the manuscripts show that he was indefatigable in seeking to acquire knowledge from every possible source, either by obtaining the loan of books or treatises, or by application to those interested in the same studies. From the astrologers then to be found at Ludovic's court — Ambrogio da Rosate and the others — he

learnt nothing. He rated their wisdom on a par with that of the alchemists and the seekers after perpetual motion. His study of the heavens differed from theirs as much in method as in purpose. His instruments were scientific, and even at times suggestively modern. The line in the Codice Atlantico, 'construct glasses to see the moon large', (fa occhiali da vedere la luna grande) refers, however, only to the use of magnifying glasses; the invention of the telescope is to be assigned to the century following.

At the commencement of the sixteenth century, the Ptolemaic theory of the Universe was still held in universal acceptance. Leonardo at first accepted it, and in his earlier writings the earth is represented as fixed, with the sun and moon revolving round it. He ended at some stage farther on in the path of modern discovery. On a page of mathematical notes at Windsor he has written in large letters, 'the sun does not move' (il sole no si muove).

He has been spoken of as the forerunner of Francis Bacon, of James Watt, of Sir Isaac Newton, of William Harvey. He cannot be said to have anticipated the discoveries with which their names are associated. It may, however, be claimed that he anticipated the methods of investigation which, when pursued to their logical issue, could not but lead to these discoveries.

The great anatomist Vesalius, after having given up his Chair of Anatomy in 1561 in order to become the court physician at Madrid, spoke of himself as still looking forward to studying 'that true bible as we count it of the human body and of the nature of man'. Sir Michael Foster takes these words as the keynote of the life-work of Vesalius : 'the true bible to read is nature itself, things as they are, not the printed pages of Galen or another; science comes by observation not by authority'. In method Leonardo was the forerunner of Vesalius, and consequently of William Harvey, whose great work was the outcome of Vesalius's teaching. No passage in his writings constitutes an anticipation of Harvey's discovery. He knew that the blood moved just as he also knew that the sun did not move, but the law of the circulation of the blood was as far beyond the stage at which his deductions had arrived as was the discovery of Copernicus. It was his work to establish, even before the birth of Vesalius, that 'science comes by observation not by authority'. Yet he was no mere empiric. He knew the authorities. He quotes in his manuscripts from Mundinus's *Anatomia*, and he must have known the work of

Galen to which Mundinus served as an introduction. At a time when the Church 'taught the sacredness of the human corpse, and was ready to punish as a sacrilege the use of the anatomist's scalpel', Leonardo practised dissection; and he suffered in consequence of his temerity, since it was subsequent to the malicious laying of information concerning these experiments that the withdrawal of the papal favour brought about his departure from Rome in 1515. Of such temerity the anatomical drawings are a rich harvest. The pall of authority was thrown aside; the primary need was for actual investigation, and of this they are a record. He would agree, he says, as to it being better for the student to watch a demonstration in anatomy than to see his drawings, 'if only it were possible to observe all the details shown in these drawings in a single figure; in which, with all your ability, you will not see nor acquire a knowledge of more than some few veins, while, in order to obtain an exact and complete knowledge of these, I have dissected more than ten human bodies, destroying all the various members and removing even the very smallest particles of the flesh which surrounded these veins, without causing any effusion of blood other than the imperceptible bleeding of the capillary veins'.

It was after his examination of these drawings that the great anatomist Dr. William Hunter wrote that he was fully of opinion that 'Leonardo was the best Anatomist at that time in the world'.

Coleridge called Shakespeare 'myriad-minded'. If the Baconian contention were established the result would afford a parallel to the myriad-mindedness of Leonardo. Morelli speaks of him as 'perhaps the most richly gifted by nature among all the sons of men'. Equally emphatic is the tribute of Francis I recorded by Benvenuto Cellini: 'He did not believe that any other man had come into the world who had attained so great knowledge as Leonardo, and that not only as sculptor, painter, and architect, for beyond that he was a profound philosopher.'

In regard to this undefined, ungarnered knowledge, the prevalent note of the early biographers is frankly the marvellous. To us his personality seems to outspan the confines of his age, to project itself by the inherent force of its vitality down into modern times and so to take its due place among the intuitive influences of modern thought. To them, on the other hand, his personality projecting beyond the limits of his own age seemed to stretch back into the age of legend, to gather something of its insouciance and its mystery. The figure — never sufficiently

to be extolled for beauty of person — wandering through princes' courts improvising songs, bearing a lute as a gift from one patron to another, and playing upon it in such skilled fashion that that alone out of all the arts of which he had knowledge would suffice as 'open sesame' to win him welcome, seems indeed rather to have its habitation in Provence at the close of the twelfth century than to be that of a contemporary and fellow-citizen of Machiavelli and Savonarola. In lieu of any such period of toilsome apprenticeship as Vasari's biographies lead us customarily to expect, there seems almost a Pallas-like maturity at birth. The angel painted by him when an apprentice causes his master to abandon the use of the brush, in chagrin that a mere child had surpassed him; and so, in like manner, we are told that a monster which he painted on a shield filled his own father with dismay. Unsatisfied with this mastery of the arts he sought to discern the arcana of Nature; and whither the quest had led him it was not for a mere biographer to say. But each will help us to conjecture, with hints more expressive than words, and less rebuttable. Leonardo's scornful references to the pretended wisdom of alchemists, astrologers and necromancers lay hidden meanwhile in the manuscripts, not available to contravene such suppositions.

The personality as represented in the early biographies is substantially that which is expressed in the phrase of Michelet, 'Léonard, ce frère italien de Faust'. It tells of him that he chose rather to know than to be, and that curiosity led him within the forbidden portals. It represents in fact the popular medieval conception of scientific study. Much of the modern aesthetic appreciation is in its essential conception a more temperate restatement of the same point of view. Errors — or at any rate some of them! — are corrected in the light of the results of critical research from Amoretti downwards: the outlook, nevertheless, remains that of Vasari and the Anonimo Fiorentino. Ruskin's dictum, that 'he debased his finer instincts by caricature and remained to the end of his days the slave of an archaic smile', is at one with the opinion of the folk of Wittenberg who lamented Faust's use of the unhallowed arts which had made him Helen's lover. The true analogy lies not with Faust but with Goethe, between whom and Leonardo there is perhaps as great a psychological resemblance as ever has existed between two men of supreme genius.

In each the purely artistic and creative faculties became subordinate, mastered by the sanity of the philosophical faculties.

In each alike the restless workings of the human spirit desiring to *know*, ranged over the various mediums of artistic expression, tempered them to its uses, and finally passed on, looking beyond the art to the thought itself, unsatisfied with what — even in its perfection of utterance — was but a pale reflex of the phenomena it would observe. The two parts of Goethe's Faust-drama symbolize the gradual change of purpose, and may perhaps serve to represent Leonardo's two spheres of activity. Verrocchio's *bottega* and all the influences of the art-world of Florence in the Quattrocento were for him tutelage and training, as the medieval chap-book legends and the newly-arisen literature of the Romantic School were for the poet of Weimar. The result in each case was limpid, serene, majestic, for the elements which had gone to the making of it had been fused molten in the flame-heat of genius. Yet the man behind the artist is still unsatisfied. He never shares the artist's accomplishment with such measure of absorption as characterized Raphael and Giovanni Bellini. He has something of the aloofness of Faust. There is that within him which art's appeal to the senses never kindled into life, never impelled to utter to one of its moments the supreme shibboleth of Hedonism, 'Stay, thou art so fair'. All the allurements of the medieval chap-book legend were revealed in the first part of the Faust-drama; then, this invocation being as yet unuttered, the thinker essays the problem. No beaten footsteps as before in this new avenue of approach. No clear limpidity of ordered effort. Titanic energy struggles painfully amid the chaos of dimly-perceived primeval forces. The result — even the very effort itself — according to much critical opinion, was an artistic mistake.

The same judgment was passed on Leonardo's work as philosopher and scientist by the earliest of his biographers. Yet in each case the thinker is nearer to the verities. Faust is regenerated by the service of man from out of the hell of medieval tradition. It was the cramping fetter of medieval tradition upon thought which Leonardo toiled to unloose. It was his aim to extend the limits of man's knowledge of himself, of his structure, of his environments, of all the forms of life around him, of the manner of the building up of the earth and sea, and of the firmament of the heavens. To this end he toiled at the patient exposition of natural things, steadfastly, and in proud confidence of purpose. 'I wish', he says, 'to work miracles: I may have fewer possessions than other men who are more tranquil and than those who wish to grow rich in a day.'

Inchoate and comparatively barren of result as was his investigation of natural phenomena, it nevertheless was actual investigation, and it attained results.

We may instance the passages in the manuscript formerly at Holkham Hall, in which the fact of fossil shells being found in the higher mountain ridges of Lombardy is used by a process of deductive reasoning to show how at one time the waters covered the earth. The hypothetical argument that the presence of these shells is to be attributed to the Flood, he meets by considering the rate of the cockle's progress. It is a creature possessed of no swifter power of motion when out of water than the snail. It cannot swim, but makes a furrow in the sand by means of its sides, and travels in this furrow a space of three to four braccia daily, and by such a method of progression it could not in forty days have travelled from the Adriatic to Monferrato in Lombardy, a distance of two hundred and fifty miles. Neither is it a case of dead shells having been carried there by the force of the waves, for the living are recognizable by the shells being in pairs. Many other passages in the manuscripts might be cited to show by what varied paths he anticipated the modern methods of scientific investigation. The words which Pater uses of the Renaissance of the fifteenth century, 'in many things great rather by what it designed or aspired to do than by what it actually achieved' — applicable to Leonardo in respect of his work as an artist — are no whit the less applicable in reference to his work in science. Painting and sculpture filled only two of the facets of a mind which, as a crystal, took the light from whatever quarter light came. As, however, it was in these arts that he accomplished most, so such of his writings as treat of them are on the whole the most practical. In science, for the most part he heralded the work of others: in respect of his writings on art, we may apply to him the words which Dürer uses of himself in a similar connection: 'what he set down with the pen he did with the hand'. It is this very factor of experience working in the mind which at times causes an abrupt antithesis, in the transition from the general principle to discussion of the means whereby it should be realized. His work may perhaps be considered to lose somewhat of its literary value in consequence, but it acquires an almost unique interest among treatises on art by its combination of the two standpoints of theory and practice. Of this, one of the most striking instances occurs in a passage which is only to be found in the recension of the treatise on 'Painting' in the Vatican (Ludwig, cap. 180). Leonardo

there sums up, tritely and profoundly, what should be the painter's purpose: 'a good painter has two chief objects to paint, man and the intention of his soul; the former is easy the latter hard'; after which follows the eminently reasonable, if perhaps unexpected, explanation, 'because he has to represent it by the attitudes and movements of the limbs'; and the knowledge of these, he proceeds to say, should be acquired by observing the dumb, because their movements are more natural than those of any other class of persons. This very practical direction how to approach towards the realization of an apparently abstract aim is entirely characteristic of his intention. The supreme misfortune, he says, is when theory outstrips performance. This essential practicality of mind brought about the result that in the more abstract portions of this branch of his writings his zest for first principles is most apparent. The sun, the origin of light and shade, is recognized as the first artist, and we are told that 'the first picture consisted merely in a line which surrounded the shadow of a man cast by the sun upon a wall'; and the comparison of poetry and painting resolves itself into a consideration of the relative importance of the senses to which the two arts make their appeal.

It is perhaps in the passages indicating the manner in which particular scenes and actions should be represented in art that Leonardo's powers as a writer find their most impressive utterance. His natural inclination impelled him to the contemplation of the vast and awe-inspiring in Nature; but in these terse, vivid, analytic descriptions, the consideration of the ultimate purpose operates throughout to restrain and co-ordinate. The descriptive passage entitled 'The way to represent a battle', in which the effect is built up entirely by fidelity of detail, forms an absolute triumph of realism. There can be no possibility of difference of opinion as to how Leonardo regarded warfare. It was a grim necessity, and he was himself busied on occasions in devising its instruments; but he had no illusions as to its real nature, he characterizes it elsewhere as 'most bestial madness' (bestialissima pazzia). Here, however, he never suffers his pen to digress from the work of simple description. To generalize would be alien to his purpose, which is to show how to portray a battle in progress. Consequently he shows what it is that is actually happening amid the clouds of dust and smoke and the rain of gunshot and falling arrows; and describes tersely, graphically, relentlessly, the passions and agonies of the combatants as shown in their faces and their actions, the bitterness of the deaths of the vanquished, the

fury and exhaustion of the victors and the mad terror of the horses, since these should find a place in the work of whosoever would represent war; 'and see to it', he says in conclusion, 'that you make no level spot of ground that is not trampled over with blood'. The passage enables us in part to realize what he sets himself to represent in the picture of the Battle of Anghiari. It is, however, far more than a mere note for a picture. It possesses an interest and value apart either from this fact or from the mastery in the art of writing which it reveals. Its ultimate value is moral and didactic. He forbears to generalize but constrains the reader in his stead. His description is of the identical spirit which has animated the creations of Tolstoy and Verestchagin. Like these, Leonardo seeks to make war impossible, by showing it stripped of all its pageantry and trappings, in its naked and hideous reality.

The passages which describe a tempest and a deluge, and their representation in painting, possess the same vigorous realism and fidelity of detail, and contain some of Leonardo's most eloquent and picturesque writing; and among the other notes connected with pictures we may instance that for the 'Last Supper', descriptive of the actions of the disciples, which, although of far slighter mould than any of the passages already referred to, yet possesses a restrained but very distinct dramatic power. These same qualities may be discerned perhaps even to more advantage in one of the very rare comments on public events which are to be found in his writings. After Ludovic Sforza's attempt to regain possession of Lombardy had ended with his defeat and capture at the battle of Novara in April 1500, Leonardo wrote among notes on various matters, 'The Duke has lost his State, his possessions, and his liberty, and he has seen none of his works finished'. (Il Duce perse lo Stato e la roba e la libertà, e nessuna sua opera si fini per lui.) Leonardo was a homeless wanderer in consequence of the events referred to, and one of the works of which the Duke had not witnessed the completion was that of the statue on which Leonardo had been engaged intermittently during sixteen years, and the model of which had served as a target for the French soldiery; but this terse impassive comment is the only reference to these occurrences found in his writings. There is a certain poignant brevity and concentration in the sentence, which suffices even to recall some of the most inevitable lines of Dante.

It is within the narrow limits of the short sentence and the apothegm that Leonardo's command of language is most luminous. In some of

these the thought expressed is so wedded to the words as scarcely to suffer transference. 'Sì come una giornata bene spesa dà lieto dormire così una vita bene usata dà lieto morire' must lose something of its grace in any rendering. Certain of these sentences record the phenomena of Nature so simply as to cause us almost to doubt whether they are intended to do more than this. 'All the flowers which see the sun mature their seed, and not the others, that is those which see only the reflection of the sun', is perhaps written as an observation of Nature without thought of a deeper meaning; but it is hard to suppose that a similar restriction applies to the sentence: 'tears come from the heart not from the brain'; although it is found in a manuscript which treats of anatomy.

It would seem that it was natural to him as a writer to use words as symbols and figuratively, thus employing things evident and revealed in metaphor. Of this habit of veiled utterance the section of his imaginative writings known as 'the Prophecies' affords the most impressive and sustained series of instances. Some few of these are, as their name implies, a forecast of future conditions; many attack the vices and abuses of his own time. In the succinct, antithetical form of their composition Leonardo apparently created his own model.

There are questions more intimate than any of those which arise from the consideration of his achievement in these various arts and sciences; questions which the mere number of these external interests tends to veil in comparative obscurity, causing us to regard Leonardo almost as a resultant of forces rather than as an individual, to see in him as it were an embodiment of the various intellectual tendencies of the Renaissance — as though the achievements were the man. The figure crosses the stage of life in triumph, playing to perfection many parts. But of these enough. Let us try to come nearer, to get past the cloak of his activities, and essay to 'pluck the heart out of this mystery'. As a means towards this end, let us consider his attitude with regard to certain of the problems of life.

His writings inculcate the highest morality, though rather as a reasoned process of the mind than as a revelation from an external authority. He preserves so complete a reticence on the subject of doctrinal belief as to leave very little base for inference as to his faith or lack of faith. The statement of Vasari, that he did not conform to any religion, deeming it better perhaps to be a philosopher than a Christian, was omitted in the second edition of the *Lives*, and may therefore be

looked upon as probably merely a crystallization of some piece of Florentine gossip. It would be idle to attempt to surmise as to the reason of the withdrawal. To whatever cause this may have been due, its significance is no whit the less as outweighing a mass of suggestion and vain repetition on this subject by later writers. In temperament Leonardo has something akin to certain of the precursors of the Reformation. In any conflict between the dictates of reason and of authority he would be found on the side of freedom of thought. 'Whoever', he wrote, 'in discussion adduces authority uses not his intellect but rather memory.'

The cast of his mind was anti-clerical. His indignation at the abuses and corruption of the Church found expression in satire as direct and piercing as that of Erasmus. His scorn of the vices of the priesthood, of their encouragement of superstition, of the trade in miracles and pardons, which is eloquently expressed in the section of his writings known as 'the Prophecies', may not unnaturally have earned for him the title of heretic from those whom he attacked. His quarrel lay, however, not with the foundations on which faith rested, but with what he conceived to be its degradation in practice by its votaries. His own path lay along the field of scientific inquiry; but where the results of this research seemed at variance with revealed truth, he would reserve the issue, disclaiming the suggestion of antagonism. Nature indeed cannot break her own laws. The processes of science are sure, but there are regions where we cannot follow them. 'Our body is subject to heaven, and heaven is subject to the spirit.' So at the conclusion of a passage describing the natural origin of life, he adds, 'I speak not against the sacred books, for they are supreme truth'. The words seem a protest against the sterile discussion of these things. There is, indeed, a reticence in the expression of the formulas of faith, but the strands of its presence may be seen in the web of life.

The impelling necessity to use life fully is the ever-recurrent burden of his moral sayings:

'Life well spent is long.'

'Thou, O God, dost sell unto us all good things at the price of labour.'

'As a well-spent day brings happy sleep, so life well used brings happy death.'

This vision of the end is steadfast. Death follows life even as sleep rounds off the day, and as we work well in the day, so sleep when it comes is happy and untroubled. During the passing of the day there is

so much to be done, such opportunity to construct and to observe, so much knowledge to be won about this world wherein the day is passed, that there is scarce time remaining in which to stand in fear and wonder at thought of what chimeras the coming shadow may hold within it. It is better to use to-day than to spend it by questioning of to-morrow. Duty in life is clear and we must follow it. When he speaks of what comes after, it is with that hesitance common to all, unless to speak of it be made habituate by custom, for to all, whatever be their belief, there yet remains something unknowable in the conditions of the change.

In one of the most beautiful passages of his writings — a fragment on time, the destroyer — Leonardo describes Helen in her old age as looking into her mirror and seeing there the wrinkles which time had imprinted on her face, and then weeping, and wondering why she had been twice carried away. Beautiful as is the description the hand which penned it is pre-eminently that of the scientist; we seem to see the anatomist at work with the scalpel, so minute is the observation therein revealed as to the effect of age and of the relentless approach of death upon the human frame.

'In her the painter had anatomized Time's ruin.'

And yet, as modern erudition in the person of the late Gerolamo Calvi has recently shown, Leonardo was not the original author of the passage. He amplified it and transformed it into a richer harmony by placing the apostrophe to Time the destroyer at the beginning as well as at the end, but the description of Helen he found in Ovid's *Metamorphoses* (Book xv, ll. 232-6).

The fact illustrates the difficulty of interpreting the contents of the Notebooks. They contain matter some of it unoriginal and some of this doubtless is as yet unidentified.

The frequent recurrence in his writings and in his drawings and grotesques of the physical tokens of decay and death argues no morbid predilection, such as that shown by the painters of the *danse macabre*. It forms a proportioned part of his study and 'patient exposition' of the origin and development of the whole structure of man. In the results as we may read them, there is no incursion of the personal note. His attitude is always that of an observer, looking with curious eyes, noting all the phenomena of physical change, but yet all the while preserving a strange impassivity. He never in any of his works or in his manuscripts gives the suggestion of possessing any of that regret at the

passing of time which rings through Giorgione's sun-steeped idylls. Indeed, from all such lament he expressly dissociates himself. Time, he maintains, stays long enough for those who use it. The mere fact of the inevitability of death forbids regret. It therefore cannot be an evil. He speaks of it as taking away the memory of evil, and compares it with the sleep which follows after the day. The thought of this sleep brings silence: when on rare occasion the silence is broken, he stands with Shakespeare and Montaigne, revealing, as they do, when they address themselves to the same question, a quiet confidence, serene and proud.

The author of *Virginibus Puerisque*, discoursing whimsically upon the incidence and attributes of the tender passion, professes his utter inability to comprehend how any member of his own sex, with at most two exceptions, can ever have been found worthy to be its object. 'It might be very well', he says, 'if the Apollo Belvedere should suddenly glow all over into life, and step forward from the pedestal with that god-like air of his. But of the misbegotten changelings who call themselves men and prate intolerably over dinner-tables, I never saw one who seemed worthy to inspire love — no, nor read of any except Leonardo da Vinci and perhaps Goethe in his youth.'

The suggestion as to the Apollo Belvedere is in entire harmony with the association of the names which follow. For if it had ever come to pass, as is conjectured in Heine's fantasy, that the gods of Greece, after their worship ceased, fallen on days of adversity, and constrained to baser uses, had walked the earth as men, surely no lives whereof record holds had come more naturally to Apollo's lot than would those of Goethe and Leonardo.

It would be vain to attempt to find better instances, yet these give only a capricious support at best to Stevenson's contention. They afford far more proof of his amazing temerity in attempting to view the kingdom of sentiment from the feminine standpoint.

These two names he ranks together in isolation from the rest of their sex — and this in respect precisely of that condition wherein the records of their lives reveal the least resemblance. Goethe was as susceptible and almost as fickle as Jupiter himself. The story of his heart is a romance with many chapters, each enshrining a new name, and all ending abruptly at the stage at which the poet remembers — at times somewhat tardily — the paramount claims of his art.

But in the case of Leonardo there are no grounds for supposing that

any one such chapter was ever begun. None of his biographers connect his name with that of any woman in the way of love, nor do his own writings afford any such indication. They show that he lived only for the things of the mind. He would seem to have renounced deliberately all thought of participation in the tenderness of human relationship. He looked upon it as alien to the artist's supreme purpose: he must needs be solitary in order to live entirely for his art. His conception of the mental conditions requisite for the production of great art presupposes something of that isolation expressed in Pater's phrase: 'each mind keeping as a solitary prisoner its own dream of a world'.

The praise of solitude has ever been a fecund theme, although much of the fervour of its votaries has resulted in little more than a reverberation of the monkish jingle, 'O beata solitudo, O sola beatitudo.' In so far as praise of solitude is dispraise of the world and one's fellow-men and the expression of desire to shun them and their activities, it is a sterile thing and worse. Solitude is unnatural and only the use of it can justify the condition. Maybe that even then the dream will never come to birth! Certain it is that if it does we must suffer the pangs alone!

Concentration of the mind comes by solitude; and in this, according to Leonardo, its value to the artist consists. (Se tu sarai solo tu sarai tutto tuo.) 'If you are alone you belong entirely to yourself. If you are accompanied even by one companion you belong only half to yourself, or even less in proportion to the thoughtlessness of his conduct. . . . If you must have companionship choose it from your studio; it may then help you to obtain the advantages which result from different methods of study.'

Such companionship of the studio implies some such measure of equality of attainment as it can never have been his own lot to meet with after leaving the circle of Verrocchio and the art world of Florence. His own lesser companions of the studio were his pupils and servants, and the only one of these whom he admitted to any degree of personal intimacy was Francesco de' Melzi, who seems to have stood to him in the concluding years of his life almost in the position of a son to a father.

Behind all his strength lay springs of tenderness; in life confined within the strait limits whereby his spirit proposed that its work should be more surely done, in his art they are manifest, therein revealing the repression of his life. His pictures are now so few that it would be to his drawings that we should chiefly look for support of this statement,

and of these primarily perhaps to the many studies for Madonna pictures, and the sketches of children made in connection with them; also, however, to the two versions of the composition of the Madonna and Child with St. Anne. The differences between that in Burlington House and that in the Louvre show the artist's gradual growth of purpose. One motive, however, is found in both, namely that the Madonna is represented as so entirely absorbed in her Child that she is entirely unconscious of aught else. With the exception of the Madonna della Seggiola, and perhaps certain others of Raphael's Madonnas, there is no Madonna picture in Italian art in which the conception is more human or the ecstasy of motherhood is rendered with greater tenderness. So 'l'art console de la vie'; and the same may be said in Leonardo's case of Nature perhaps even more truly than of art. If indeed any thought of consolation can be suffered in connection with a life so confident and full! For man's work is his ultimate self. Such human hopes as begin and end in the individual are puny even in their highest fulfilment, and the processes of Nature, whatever their final end, seem eternal in contrast with their transience.

He interpreted man's highest aim to consist in seeking to know and to hand on the lamp of knowledge.

A RECORD OF THE MANUSCRIPTS

In the opening lines of the volume of manuscript notes 'begun at Florence in the house of Piero di Braccio Martelli, on the 22nd day of March, 1508', now in the British Museum (Arundel MSS. 263), Leonardo explains the method of its composition. The passage may serve to summarize the impression made by the whole mass of Leonardo's manuscripts. 'This', he says, 'will be a collection without order, made up of many sheets which I have copied here, hoping afterwards to arrange them in order in their proper places according to the subjects of which they treat; and I believe that before I am at the end of this I shall have to repeat the same thing several times; and therefore, O reader, blame me not, because the subjects are many, and the memory cannot retain them and say "this I will not write because I have already written it". And if I wished to avoid falling into this mistake it would be necessary, in order to prevent repetition, that on every occasion when I wished to transcribe a passage I should always read over all the preceding portion, and this especially because long periods of time elapse between one time of writing and another.' Certain pages in the volume of manuscript in the British Museum would indeed seem to be of a much earlier date than this introductory sentence, and the whole body of the manuscripts, as may be shown by the time-references contained in them, extend over a period of some forty years, from Leonardo's early manhood to his old age. He commenced them during the time of his first residence in Florence, and was still adding to them when at Amboise.

The contents of this 'collection without order' are so diversified as to render wellnigh impossible any attempt at formal classification. In addition to the numerous fragments of letters, the personal records, the notes relating to his work as an artist, and the fragments of imaginative composition which are to be found therein, it presents by far the most complete record of his mental activity, and this may be said without exaggeration to have extended into practically all the avenues of human knowledge. These manuscripts serve in a sense to show the mind in its workshop, busied in researching, in making conjecture, and in recording phenomena, tempering to its uses, in so far as human instrument may, the vast forces of Nature.

He projected many treatises which should embody the results of these researches. Notes in the manuscripts themselves record the various stages of their composition. Some still exist in a more or less complete form. Of the fragments of others the order of arrangement is now only a matter of conjecture. In the manuscripts at Windsor, which treat mainly of anatomy, a note, dated April 2nd, 1489, speaks of writing the book 'about the human figure'. The manuscript given to the Ambrosian Library by Cardinal Federico Borromeo, now MS. C of the Institut de France, which is a treatise on light and shade, contains a note that 'on the 23rd day of April 1490, I commenced this book and recommenced the horse' — the latter reference being to the equestrian statue of Francesco Sforza. In August 1499 a note in the Codice Atlantico states that he was then writing 'upon movement and weight'. These dates are, however, of relatively less importance, because each of these subjects occupied his thoughts during a long period of years. The two first formed a part of the artist's complete equipment as Leonardo conceived it: the third found practical issue in his undertakings in canalization and engineering in Lombardy, Tuscany, Romagna and elsewhere. In connection with the former of these two divisions of his activities may be cited the treatise on the nature of water formerly in the possession of the Earl of Leicester, and the same subject is also treated of among others in MS. F of the Institut, which, according to a note, was commenced at Milan on September 12th, 1508.

The manuscripts as a whole are picturesquely described in the diary of a certain Antonio de Beatis, the secretary of the Cardinal of Aragon, who with his patron visited Leonardo at Amboise in October 1517. The many wanderings of the painter's life were then ended, and he was living with Francesco Melzi and his servant Battista de Villanis in the manor house of Cloux, the gift of Francis I. The diary relates that he showed his guests three pictures, the St. John, the Madonna with St. Anne, and the portrait of a Florentine lady, painted at the request of Giuliano de' Medici, which cannot now be identified. It further states that paralysis had attacked his right hand, and that therefore he could no longer paint with such sweetness as formerly, but still occupied himself in making drawings and giving instruction to others. (May the inference be that he then drew with the left hand? If so he presumably used it in the manuscripts, which are written backwards.)

'This gentleman has', he continues, 'written of anatomy with such

detail, showing by illustrations the limbs, muscles, nerves, veins, ligaments, intestines and whatever else there is to discuss in the bodies of men and women, in a way that has never yet been done by anyone else. All this we have seen with our own eyes; and he said that he had dissected more than thirty bodies, both of men and women, of all ages. He has also written of the nature of water, of divers machines and of other matters, which he has set down in an infinite number of volumes all in the vulgar tongue, which if they should be published will be profitable and very enjoyable.'

This description of the manuscripts — the only one by an eyewitness during Leonardo's lifetime—leads to the supposition that, if not all, at any rate by far the greater part of them were in Leonardo's possession at the time that he went to France, and were at Cloux at the time of his death.

The manuscripts then passed into the possession of Francesco Melzi, to whom Leonardo in his will, dated April 23rd, 1518, bequeathed 'in return for the services and favours done him in the past', 'each and all of the books of which the said Testator is at present possessed, together with the other instruments and portraits which belong to his art and calling as a Painter'. Melzi returned to Milan shortly after Leonardo's death and took the manuscripts with him, and four years later a certain Alberto Bendedeo, writing from Milan to Alfonso d'Este, said that he believed that the Melzi whom Leonardo made his heir was in possession of 'such of his notebooks as treated of anatomy and many other beautiful things'.

Vasari visited Milan in 1566, and he states that Melzi whom he saw, and who was then 'a beautiful and gentle old man', possessed a great part of Leonardo's papers of the anatomy of the human body, and kept them with as much care as though they were relics. Some of the manuscripts had already at this time passed into other hands, for Vasari refers to some which treated of painting and methods of drawing and colouring as being then in the possession of a certain Milanese painter whose name he does not mention. The care which had been taken of those in Melzi's possession ceased at his death, which occurred in 1570. Some years later no restriction was placed by Melzi's heirs upon the action of a certain Lelio Gavardi di Asola, a tutor in the Melzi family, who took thirteen of the volumes of manuscripts with him to Florence for the purpose of disposing of them to the Grand Duke, Francesco. The duke's

death, however, prevented the realization of this project, and Gavardi subsequently took the volumes with him to Pisa. Giovanni Ambrogio Mazzenta, a Milanese who was then at the University of Pisa studying law, remonstrated with Gavardi upon his conduct, and with such success that on Mazzenta's return to Milan in 1587 he took the volumes with him for the purpose of restoring them to the Melzi family. When, however, he attempted to perform this duty Dr. Orazio Melzi was so astonished at his solicitude in the matter that he made him a present of all the thirteen volumes, telling him further that there were many other drawings by Leonardo lying uncared-for in the attics of his villa at Vaprio. In 1590 Giovanni Ambrogio Mazzenta joined the Barnabite Order and the volumes were then given by him to his brothers. They seemed to have talked somewhat freely about the incident, and in consequence, according to Ambrogio Mazzenta's account, many people were filled with the desire to obtain similar treasures, and Orazio Melzi gave away freely drawings, clay models, anatomical studies, and other precious relics from Leonardo's studio.

Among the others who thus came into possession of works by Leonardo was the sculptor Pompeo Leoni, who was employed in the service of the King of Spain. He afterwards induced Orazio Melzi, by the promise of obtaining for him official honours and preferment, to appeal to Guido Mazzenta, in whose possession they then were, to restore the volumes of Leonardo's manuscripts so that he might be enabled to present them to Philip II. Melzi's entreaties were successful in obtaining the return of seven volumes, and three of the others subsequently passed into Pompeo Leoni's possession on the death of one of the Mazzentas. Of the remaining three, one according to Mazzenta's account was given to the Cardinal Federico Borromeo, and passed into the Ambrosian Library which he founded in 1603; another was given to the painter Ambrogio Figini, who afterwards bequeathed it to Ercole Bianchi; it was subsequently in the possession of Joseph Smith, English Consul at Venice, and with the sale of his effects in 1759 all record of it ends; the third was given to Charles Emmanuel, Duke of Savoy, and nothing further is known as to its history. Professor Govi has conjectured that it was perhaps burnt in one of the fires which occurred in the Royal Library at Turin in 1667 or 1679.

Some of the volumes of the manuscripts which had passed into the possession of Pompeo Leoni were afterwards cut in pieces by him in

order to form one large volume from the leaves, together with some of the drawings which he had obtained from Melzi's villa at Vaprio. This volume, known as the Codice Atlantico on account of its size, contains four hundred and two sheets and more than seventeen hundred drawings, and bears on its cover the inscription:

DISEGNI DI MACHINE ET
DELLE ARTI SECRETI
ET ALTRE COSE
DI LEONARDO DA VINCI
RACOLTI DA
POMPEO LEO
NI

Apparently the collector's instinct proved stronger in Pompeo Leoni than his original intention. He was subsequently in Madrid, where he was engaged in executing bronzes for the royal tombs in the Escurial, but there is no evidence to show that he ever parted with any of Leonardo's manuscripts to Philip II. The Codice Atlantico remained in his possession until his death in 1610, and then passed to his heir, Polidoro Calchi, by whom it was sold in 1625 to Count Galeazzo Arconati. Two of Leonardo's manuscripts in Pompeo Leoni's possession were included among his effects sold after his death at Madrid, and were then bought by Don Juan de Espina. It would seem probable that others of the manuscripts in Pompeo Leoni's possession descended to his heir Calchi, and from him passed into the possession of Count Arconati, because the latter in 1636 presented twelve volumes of Leonardo's manuscripts to the Ambrosian Library at Milan. The volume which Mazzenta had given to Cardinal Federico Borromeo had already been placed there in 1603, and in 1674 yet another volume of Leonardo's manuscripts was added by the gift of Count Orazio Archinti.

Of the list of twelve manuscripts as described in Count Arconati's deed of gift to the Ambrosian Library, the second was afterwards lost, and the fifth was removed from the Library — it being, as the description shows, identical with the manuscript of Leonardo's which in about the year 1750 was bought from a certain Gaetano Caccia of Novara by Carlo Trivulzio and is now in the possession of Prince Trivulzio at Milan. The remaining ten manuscripts of the Arconati donation,

together with the two from Cardinal Federico Borromeo and Count Archinti respectively, were in the Ambrosian Library until 1796. There was then also with them a manuscript of ten sheets which treated of the eye, the *provenance* of which is unknown, but which it is conjectured had been substituted for the manuscript now in the collection of Prince Trivulzio. These thirteen manuscripts were all removed to Paris in the year 1796 in pursuance of the decree of Bonaparte as General-in-Chief of the Army of Italy of 30 Floreal An. IV (May 19th, 1796), providing for the appointment of an agent who should select such pictures and other works of art as might be worthy of transmission to France. The words of the decree authorizing and justifying the removal arrest attention by the naivety of their ὕβρις. 'All men of genius', it ran, 'all who have attained distinction in the republic of letters are French, whatever be the country which has given them birth'. (Tous les hommes de génie, tous ceux qui ont obtenu un rang distingué dans la république des lettres, sont Français, quelque soit le pays qui les aît vus naître.)

The Codice Atlantico was in the Bibliothèque Nationale at Paris in August 1796. The other twelve volumes of the manuscripts were deposited in the Institut de France. In 1815 the Austrian Ambassador, as representing Lombardy, made application for the return of all the Leonardo manuscripts. The request was complied with as regards the Codice Atlantico, which was then restored to the Ambrosian Library at Milan, but the twelve volumes in the library of the Institut de France were apparently overlooked, and there they have since remained.

On their arrival in France the manuscripts were described by J. B. Venturi, who then marked them with the lettering whereby they have subsequently been distinguished. He gave their total number as fourteen, because MS. B contained an appendix of eighteen pages which could be separated and considered as the fourteenth volume.

This manuscript is identical with No. 3 in the Arconati donation, which is described as having at the end a small 'volumetto' of eighteen pages containing various mathematical figures and drawings of birds. This 'volumetto' seems in fact to have been treated somewhat as Venturi suggests by Count Guglielmo Libri, who frequently had access to the manuscripts in the Institut de France in the early part of last century,

and who apparently abstracted it at some time previous to 1848, at which date its loss was discovered. In 1868 it was sold by Libri to Count Giacomo Manzoni of Lugo, and in 1892 it was acquired from Count Manzoni's heirs by M. Sabachnikoff, by whom it was published in the following year as *Il Codice sul Volo degli Uccelli* (edit. Piumati e Sabachnikoff, Paris, 1893). It has subsequently been presented to the Royal Library at Turin.

Two other manuscripts by Leonardo, of sixty-eight and twenty-six pages respectively, now in the Bibliothèque Nationale (Nos. 2038 and 2037), must have originally formed part of the manuscripts A and B of the Institut de France. They tally both in the dimensions of the pages and in the subjects of which they treat, and their total numbers added to those of Manuscripts A and B respectively do not amount to quite the full numbers of the leaves which these two manuscripts possessed in 1636, as described in the list of the Arconati donation.

These two manuscripts in the Bibliothèque Nationale were formerly in the collection of the late Earl of Ashburnham, who purchased them in 1875 from Count Libri, from whom, as we have seen, Count Manzoni had purchased the 'volumetto' 'On the flight of birds'. The mutilation of Manuscripts A and B of the Institut de France and the removal of the 'volumetto' were first discovered in the year 1848. It is impossible to avoid the inference that the action in each case was the work of Count Libri. The two manuscripts of the Bibliothèque Nationale have been included in the edition of the manuscripts of the Institut de France published in facsimile, with a transcript and French translation by M. Ravaisson-Mollien, in six volumes (Paris, 1880-91).

The Codice Atlantico has also been published in facsimile, with a transcript, under the direction of the Accademia dei Lincei, at Rome (1894-1904); and the manuscript in the possession of Prince Trivulzio, which as we have seen was formerly in the Ambrosian Library as one of the Arconati bequest, has been published in facsimile with a transcript by Signor Beltrami (Milan, 1892).

We may now consider the Arconati bequest from another standpoint. The count's munificence was commemorated in the following inscription which was set in marble on the wall of the staircase of the Ambrosian Library:

LEONARDI . VINCII
MANU . ET . INGENIO . CELEBERRIMI
LUCUBRATIONUM . VOLUMINA . XII
HABES . O . CIVIS
GALEAZ . ARCONATUS
INTER . OPTIMATES . TUOS
BONARUM . ARTIUM . CULTOR . OPTIMUS
REPUDIATIS . REGIO . ANIMO
QUOS . ANGLIAE . REX . PRO . UNO . TANTUM . OFFEREBAT
AUREIS . TER . MILLE . HISPANICIS
NE . TIBI . TANTI . VIRI . DEESSET . ORNAMENTUM
BIBLIOTHECAE . AMBROSIANAE . CONSECRAVIT
NE . TANTI . LARGITORIS . DEESSET . MEMORIA
QUEM . SANGUIS . QUEM . MORES
MAGNO . FEDERICO . FUNDATORI
ADSTRINGUNT
BIBLIOTHECAE . CONSERVATORES
POSUERE
ANNO MDCXXXVII

'The glorious (boasting) inscription' — so described in the *Memoirs of John Evelyn* — has naturally attracted the attention of English travellers. Evelyn records his failure to obtain a sight of the manuscripts when he visited Milan in 1646, owing to the keeper of them being away and having taken the keys, but he states that he had been informed by the Lord Marshal, the Earl of Arundel, that all of them were small except one book, a huge folio containing four hundred leaves 'full of scratches of Indians', and 'whereas', he says, 'the inscription pretends that our King Charles had offered £1000 for them, my lord himself told me that it was he who treated with Galeazzo for himself in the name and by the permission of the King, and that the Duke of Feria, who was then Governor, should make the bargain: but my lord having seen them since did not think them of so much worth'. The inscription, however, does not mention the name of the King. Addison, in his *Remarks on Several Parts of Italy* in describing his visit to Milan in 1701, mentions the Ambrosian Library as containing 'a manuscript of Leonardus Vincius, wich King James I could not procure, tho' he profer'd for it three thousand spanish pistoles'; and the monarch in question is also stated to have been James I in the fuller record of the

Arconati donation. The Duke of Feria was Governor of Milan from 1610 to 1633, during a part of the reign of both monarchs.

Apparently, however, the manuscripts only passed into the possession of Count Arconati in 1625, the year of the death of James I, and this renders it probable that the monarch referred to was Charles I. But the question of under which king has relatively little import, and with regard to the inscription, it may perhaps be well to recall the dictum of Dr. Johnson that 'in lapidary inscriptions a man is not upon oath'. The only inference that can fairly be drawn from the present instance is that the manuscripts by Leonardo now in the Royal Collection at Windsor did not form part of the Arconati Collection. This is also confirmed by the testimony of Lord Arundel, as recounted by Evelyn. That some of the Leonardo manuscripts at Windsor were once in the possession of Lord Arundel is established by the fact of the existence of an engraving of one of the drawings by Hollar, whom Lord Arundel brought from Prague and established in London. It is inscribed 'Leonardus da Vinci sic olim delineavit. W. Hollar fecit ex collectione Arundeliana'.

That some of these Windsor manuscripts were also formerly in the Collection of Pompeo Leoni is clearly shown by the fact that one of the volumes is inscribed 'Disegni di Leonardo da Vinci Restaurati da Pompeo Leoni'.

Two of the manuscripts in Pompeo Leoni's collection, as already stated, were purchased in Madrid after his death by Don Juan de Espina; and Mr. Alfred Marks — from whose important contributions to this branch of the subject in the *Athenaeum* of February 23rd and July 6th, 1878, many of the foregoing facts are derived — has shown that for one at any rate of these volumes, the Earl of Arundel was in treaty with Don Juan de Espina. The evidence of this is to be found in a note by Endymion Porter, of the date 1629, printed by Mr. Sainsbury in his *Original Unpublished Papers illustrative of the Life of Rubens*: '... of such things as my Lord Embassador S^r Francis Cottington is to send out of Spain for my Lord of Arondell; and not to forget the booke of drawings of Leonardo de Vinze w^ch is in Don Juan de Espinas hands' (p. 294). Don Juan seems for a time to have proved obdurate, for Lord Arundel wrote on January 19th, 1636, to Lord Aston, who was then ambassador to Spain: 'I beseech y^u be mindfull of D. Jhon de Spinas booke, if his foolish humour change'

(p. 299). There the record breaks off. But as Mr. Marks truly observes, there can be little doubt that eventually a change did take place in Don Juan's 'foolish humour'. At whatever date this happened the volume passed into Lord Arundel's possession. The earl may either have been negotiating for himself or for the King. If the former was the case, the book may presumably have passed into the Royal Collection at any time after 1646, when on the death of Lord Arundel his collections were partially dispersed. If it was not acquired previously the volume may have been bought in Holland by an agent of Charles II.

The earliest record of any of Leonardo's manuscripts or drawings as being in the royal possession occurs in an inventory found by Richter in the Manuscript Department of the British Museum, which states that some drawings of Leonardo da Vinci, marked with a cross, were delivered for Her Majesty's use in the year 1728.

Richter also cites a note in an inventory at Windsor Castle written at the beginning of last century, in which a drawing of Leonardo's is referred to as not having been in the volume compiled by Pompeo Leoni, but in one of the volumes in the Buonfigluolo Collection bought at Venice. Nothing apparently is known about the collection here referred to, but the note is important as tending to prove that the manuscripts by Leonardo now at Windsor were not all acquired at the same time, and did not all form part of Pompeo Leoni's collection.

The volume of manuscript now in the British Museum (Arundel MSS. 263) was certainly once in the possession of Lord Arundel. Nothing is known of its history previous to this, and whether or no it belonged to Pompeo Leoni, or was acquired by purchase from Don Juan de Espina, it would be idle to attempt to conjecture. Lord Arundel had numerous agents in various parts of Europe, who were employed in collecting antiquities and works of art. It may, however, be noted that the greater part of his collection of manuscripts was acquired by the earl himself at Nuremberg in 1636, and had formerly belonged to Wilibald Pirkheimer, the humanist, the friend of Erasmus and Dürer. If any opportunity presented itself to him, Pirkheimer would certainly have possessed himself of any manuscript of Leonardo's; but to suppose him to have done so would be to assume that some of the manuscripts passed into other hands during Leonardo's lifetime, and this, though by no means impossible, is at any rate improbable.

The only other manuscripts by Leonardo now known to exist, with

the exception of a few separate sheets of sketches and diagrams with explanatory text, are three small notebooks in the Forster Library at South Kensington, and a volume of seventy-two pages long in the possession of the Earls of Leicester at Holkham Hall but recently sold to Mr. Pierpont Morgan and believed to be now in New York. The former were acquired in Vienna for a small sum by the first Earl of Lytton and by him presented to Mr. Forster; the latter, according to a note on the title-page, once belonged to the painter Giuseppe Ghezzi, who was living in Rome at the beginning of the eighteenth century, it having presumably been acquired by the first (Holkham) Earl of Leicester, who spent some years in Rome previous to 1775, and there acquired many art treasures. Its previous history is unknown. This volume — a treatise on the nature of water — is in all probability that referred to by Rafaelle du Fresne in the sketch of Leonardo's life which appears in his edition of the *Trattato della Pittura*, published in Paris in 1651, where it is stated that 'the undertaking of the canal of the Martesana was the occasion of his writing a book on the nature, weight, and motion of water, full of a great number of drawings of various wheels and engines for mills to regulate the flow of water and raise it to a height'.

Of the manuscripts at Windsor which in the main are those that treat of anatomy, two volumes with facsimiles (60 leaves with about 400 drawings), transcripts and translations, have been issued by Messrs. Piumati and Sabachnikoff, *Dell'Anatomia Fogli A* (Paris, 1898), *Fogli B* (Turin, 1901), and the *Quaderni d'Anatomia*, six volumes (129 leaves with about 1050 drawings), by Messrs. Vangenstan, Fonahn and Hopstock (Oslo, 1911-16). Facsimiles of other leaves at Windsor were issued by Rouveyre from plates prepared for the use of Sabachnikoff. The manuscript in the British Museum and the three in the Forster Library were published in Rome by the Reale Commissione Vinciana at various dates from 1923-34, and an edition of the Leicester manuscript has been edited by Gerolamo Calvi (Milan, 1909).

As Leonardo's fame as a writer has chiefly rested upon the *Treatise on Painting*, it may not be out of place here to attempt to state the relation which this work bears to the original manuscripts.

The *Treatise* was first published by Rafaelle du Fresne, in Paris, in 1651, a French translation by Roland Fréard, sieur de Chambrai, being also issued in the same year. Du Fresne derived his text from two old copies of MS. 834 in the Barberini Library, which manuscript has

now presumably been transferred to the Vatican, at the same time as the other contents of that Library. One of these copies had been made by the Cavaliere Cassiano del Pozzo, who had given it in 1640 to M. Chanteloup, by whom it was presented to du Fresne for the preparation of his edition; the other was lent him for the same object by M. Thevenot.

Another edition of the *Treatise* was issued in 1817 by Guglielmo Manzi, who took as his text a manuscript in the Vatican Library (Cod. Vat. [Urbinas], 1270), which had formerly belonged to the Library of the Dukes of Urbino. This manuscript is by far the more complete of the two, five out of the eight books which it contains being wanting in the version followed by du Fresne. There are, however, many omissions in Manzi's edition, and the only adequate critical edition of the Vatican manuscript is that published by H. Ludwig (*Leonardo da Vinci: Das Buch von der Malerei* [Bd. xv-xviii of *Quellenschriften fur Kunstgeschichte*, etc., Edit. R. Eitelberger v. Edelberg], Vienna, 1882, Stuttgart, 1885). This contains the complete text, together with a German translation and commentary, and also an analysis of the differences which exist between the manuscripts in the Vatican and Leonardo's own manuscripts.

The Vatican manuscript probably dates from the beginning of the sixteenth century. It has been ascribed to some immediate pupil of Leonardo's, for choice either Francesco Melzi or Salai, but there is no evidence which can be held to establish this view. Its close connection with Leonardo is, however, indisputable. Whether this be the original form or no, the compilation was undoubtedly made previous to the dispersal of the manuscripts. About a quarter of the whole number of paragraphs (two hundred and twenty-five out of nine hundred and forty-four) are identical with passages in the extant manuscripts. Many others, which are not now to be found in any form in the manuscripts, yet carry their lineage incontestably, and would afford a sufficient proof, were this lacking in the chequered history of the various volumes, that some of the manuscripts have now perished: that, as with Leonardo as painter so also as writer, time has spared only the fragments of his work. The compiler of the *Treatise on Painting* had access to manuscripts, and also probably to sources of information as to the artist's intentions, of which we have no record. He presumably followed what he conceived to be the scheme of the artist's work. Nevertheless, Leonardo cannot be

adjudged directly or even indirectly responsible for the arrangement and divisions of this treatise, and it is somewhat difficult to credit him with the whole of the contents. Certain of the passages read rather as repetitions by a pupil of a theme expounded by the master.

Did Leonardo himself ever give his work definite shape? Did he write a treatise on painting or only parts of one? In Fra Luca Pacioli's dedication to Ludovic Sforza of the *De Divina Proportione*, dated February 9th, 1498, he speaks of Leonardo as having finished 'il Libro de Pictura et movimenti humani', and Dr. Ludwig, who apparently accepts this statement, puts forward the supposition that the treatise was in the possession of Ludovic and probably became lost at the time of the French invasion of Milan.

On this same occasion, according to both Vasari and Lomazzo, there also perished a treatise by Leonardo on the anatomy of the horse, which he had written in the course of his studies for the Sforza statue.

Vasari, as we have seen, mentions some writings by Leonardo 'which treat of painting and of the methods of drawing and colouring' as being then in the possession of a Milanese painter, who had recently been to see him in Florence to discuss their publication, and had taken them to Rome in order to carry his intention into effect, though with what result Vasari could not say. These writings are stated to be 'in characters written with the left hand, backwards', and therefore they cannot possibly be identical either with the Barberini or the Vatican manuscripts. Seeing that Vasari wrote during Melzi's lifetime, it is reasonable to infer that this manuscript had at an early date become separated from the others and therefore did not form part of the general mass of the manuscripts which passed into Melzi's possession at Leonardo's death, since Vasari states that he kept these as though they were relics. As to whether this manuscript was identical with the work to which Fra Luca Pacioli referred, there is no sufficient evidence on which to form an opinion. Moreover, the Frate's evidence must not be interpreted too literally. The words of the dedication of the *De Divina Proportione*, 'tutta la sua ennea massa a libre circa 200000 ascende', would naturally also suggest that the statue of Francesco Sforza was actually cast in bronze, but the general weight of evidence, including that of Leonardo's own letters, forbids any such supposition. So, in like manner, it may perhaps have been that in the case of the *Treatise on Painting* he may

have spoken of the rough drafts and fragments as though they were the completed work.

The work itself grew continually in the mind of the author. It was moulded and recast times without number, as his purpose changed and expanded in his progress along each new avenue of study that revealed afresh the kinship of art and nature. It is certain that he never wrote 'finis'. It is at any rate possible that he never halted in investigation for so long a time as would be necessary to arrange and classify what he had written — that he left all this to a more convenient season. Genius, we should remember, is not apt to be synthetic.

LIST OF ABBREVIATIONS

In the references to the manuscripts which follow these abbreviations occur:

C.A. = Codice Atlantico.
Tr. = Codice Trivulziano.
A, B, etc., to I, and K, L, M = MSS. A, B, etc., to I and K, L, M of the Library of the Institut de France.
MSS. 2037 and 2038 Bib. Nat. = Nos. 2037 and 2038, Italian MSS., Bibliothèque Nationale.
B.M. = Arundel MSS., No. 263, British Museum.
Forster I, II, III = Forster Bequest MSS. I, II, III, Victoria and Albert Museum.
Leic. = MS. formerly in possession of Earl of Leicester, now of Mr. Pierpont Morgan.
Sul Volo = MS. 'Sul Volo degli Uccelli' in Royal Library, Turin.
Sul Volo (F.M.) = 'Sul Volo' Fogli Mancanti. Fatio Collection, Geneva.
Fogli A and B = Dell' Anatomia Fogli A and B, Royal Library, Windsor.
Quaderni I-VI = Quaderni d'Anatomia I-VI, Royal Library, Windsor.
R. = J. P. Richter, *Literary Works of L. da V.*

Proem

PROEM

If indeed I have no power to quote from authors as they have, it is a far bigger and more worthy thing to read by the light of experience, which is the instructress of their masters. They strut about puffed up and pompous, decked out and adorned not with their own labours but by those of others, and they will not even allow me my own. And if they despise me who am an inventor how much more should blame be given to themselves, who are not inventors but trumpeters and reciters of the works of others?

* * * * * *

Those who are inventors and interpreters between Nature and Man as compared with the reciters and trumpeters of the works of others, are to be considered simply as is an object in front of a mirror in comparison with its image when seen in the mirror, the one being something in itself, the other nothing: people whose debt to nature is small, for it seems only by chance that they wear human form, and but for this one might class them with the herds of beasts.

C.A. 117 r. b

Seeing that I cannot choose any subject of great utility or pleasure, because my predecessors have already taken as their own all useful and necessary themes, I will do like one who, because of his poverty, is the last to arrive at the fair, and not being able otherwise to provide himself, chooses all the things which others have already looked over and not taken, but refused as being of little value. With these despised and rejected wares — the leavings of many buyers — I will load my modest pack, and therewith take my course, distributing, not indeed amid the great cities, but among the mean hamlets, and taking such reward as befits the things I offer.

I am fully aware that the fact of my not being a man of letters may cause certain arrogant persons to think that they may with reason censure me, alleging that I am a man ignorant of book-learning. Foolish folk! Do they not know that I might retort by saying, as did Marius to the Roman Patricians: 'They who themselves go about adorned in the labour of others will not permit me my own'? They will say that because of my lack of book-learning, I cannot properly express what I desire to

treat of. Do they not know that my subjects require for their exposition experience rather than the words of others? And since experience has been the mistress of whoever has written well, I take her as my mistress, and to her in all points make my appeal.

Many will believe that they can with reason censure me, alleging that my proofs are contrary to the authority of certain men who are held in great reverence by their inexperienced judgments, not taking into account that my conclusions were arrived at as a result of simple and plain experience, which is the true mistress.

These rules enable you to discern the true from the false, and thus to set before yourselves only things possible and of more moderation; and they forbid you to use a cloak of ignorance, which will bring about that you attain to no result and in despair abandon yourself to melancholy.

The natural desire of good men is knowledge.

I know that many will call this a useless work, and they will be those of whom Demetrius said that he took no more account of the wind that produced the words in their mouths than of the wind that came out of their hinder parts: men whose only desire is for material riches and luxury and who are entirely destitute of the desire of wisdom, the sustenance and the only true riches of the soul. For as the soul is more worthy than the body so much are the soul's riches more worthy than those of the body. And often when I see one of these men take this work in hand I wonder whether he will not put it to his nose like the ape, and ask me whether it is something to eat.

C.A. 119 v. a

Begun in Florence in the house of Piero di Braccio Martelli, on the 22nd day of March, 1508. This will be a collection without order, made up of many sheets which I have copied here, hoping afterwards to arrange them in order in their proper places according to the subjects of which they treat; and I believe that before I am at the end of this I shall have to repeat the same thing several times; and therefore, O reader, blame me not, because the subjects are many, and the memory cannot retain them and say 'this I will not write because I have already

written it'. And if I wished to avoid falling into this mistake it would be necessary, in order to prevent repetition, that on every occasion when I wished to transcribe a passage I should always read over all the preceding portion, and this especially because long periods of time elapse between one time of writing and another.

B.M. 1 r.

I

Philosophy

'Nature is full of infinite causes which were never set forth in experience.'

We have no lack of system or device to measure and to parcel out these poor days of ours; wherein it should be our pleasure that they be not squandered or suffered to pass away in vain, and without meed of honour, leaving no record of themselves in the minds of men; to the end that this our poor course may not be sped in vain.

C.A. 12 v. a

Our judgment does not reckon in their exact and proper order things which have come to pass at different periods of time; for many things which happened many years ago will seem nearly related to the present, and many things that are recent will seem ancient, extending back to the far-off period of our youth. And so it is with the eye, with regard to distant things, which when illumined by the sun seem near to the eye, while many things which are near seem far off.

C.A. 29 v. a

Supreme happiness will be the greatest cause of misery, and the perfection of wisdom the occasion of folly.

C.A. 39 v. c

Every part is disposed to unite with the whole, that it may thereby escape from its own incompleteness.

The soul desires to dwell with the body because without the members of that body it can neither act nor feel.

C.A. 59 r. b

[*Drawing: bird sitting in cage*]
The thoughts turn towards hope.[1]

C.A. 68 v. b

O Time, thou that consumest all things! O envious age, thou destroyest all things and devourest all things with the hard teeth of the years, little by little, in slow death! Helen, when she looked in her mirror and saw the withered wrinkles which old age had made in her face, wept, and wondered to herself why ever she had twice been carried away.

[1] The sketch at the side of this sentence serves to recall the fact that as Vasari states Leonardo was in the habit of paying the price demanded by the owners of captive birds simply for the pleasure of setting them free.

O Time, thou that consumest all things! O envious age, whereby all things are consumed![1]

C.A. 71 r. a

The age as it flies glides secretly and deceives one and another; nothing is more fleeting than the years, but he who sows virtue reaps honour.

C.A. 71 v. a

Wrongfully do men lament the flight of time, accusing it of being too swift, and not perceiving that its period is yet sufficient; but good memory wherewith Nature has endowed us causes everything long past to seem present.

Whoever would see in what state the soul dwells within the body, let him mark how this body uses its daily habitation, for if this be

[1] Gerolamo Calvi has shown in an article in the Archivio Storico Lombardo, Anno XLIX (1916) Fasc. III that the source of this passage is to be found in Ovid's *Metamorphoses*, Book XV, lines 232-6:

'Flet quoque, ut in speculo rugas aspexit aniles
Tyndaris, et secum, cur sit bis rapta, requirit.
Tempus edax rerum, tuque, invidiosa vetustas,
Omnia destruitis, vitiataque dentibus aevi
Paulatim lenta consumitis omnia morte.'

'Helen also weeps when she sees her aged wrinkles in the looking-glass, and tearfully asks herself why she should twice have been a lover's prey. O Time, thou great devourer, and thou, envious Age, together you destroy all things; and, slowly gnawing with your teeth, you finally consume all things in lingering death!' (Loeb.)

The passage as it appears in the Codice Atlantico serves to show how Leonardo in borrowing enriched the Roman poet's thought with the melody of music by introducing the apostrophe to time and envious age as prelude as well as finale:

'O tempo, consumatore delle cose, e o invidiosa antichità, tu distruggi tutte le cose e consumi tutte le cose da duri denti della vecchiezza a poco a poco con lenta morte!

Elena quando si specchiava, vedendo le vizze grinze del suo viso, fatte per la vecchiezza, piagnie e pensa seco, perchè fu rapita due volte.

O tempo, consumatore delle cose, e o invidiosa antichità, per la quale tutte le cose sono consumate.'

Immediately below this passage Leonardo wrote these words: 'this book belongs to Michele di Francesco Bernabini and his family'. It is a reasonable inference that they refer to the copy of Ovid from which the lines were taken. Farther below in writing of the same time is a fragment: 'tell, tell me how things are passing yonder and whether Caterina wishes to make . . .'

Caterina was the name of Leonardo's mother. He wrote the name when his thoughts had just been turning to the poet's description of the changes that time had made in Helen's beauty. From this has arisen the conjecture — it is nothing more! — that the sentence refers to her and that he was making some provision for her in her old age.

confused and without order the body will be kept in disorder and confusion by the soul.

C.A. 76 r. a

O thou that sleepest, what is sleep? Sleep is an image of death. Oh, why not let your work be such that after death you become an image of immortality; as in life you become when sleeping like unto the hapless dead.

Man and the animals are merely a passage and channel for food, a tomb for other animals, a haven for the dead, giving life by the death of others, a coffer full of corruption.

C.A. 76 v. a

Behold a thing which the more need there is of it is the more rejected: this is advice, listened to unwillingly by those who have most need of it, that is by the ignorant. Behold a thing which the more you have fear of it and the more you flee from it comes the nearer to you: this is misery, which the more you flee from it makes you the more wretched and without rest.

C.A. 80 v. a

Experience the interpreter between resourceful nature and the human species teaches that that which this nature works out among mortals constrained by necessity cannot operate in any other way than that in which reason which is its rudder teaches it to work.

C.A. 86 r. a

To the ambitious, whom neither the boon of life, nor the beauty of the world suffice to content, it comes as penance that life with them is squandered, and that they possess neither the benefits nor the beauty of the world.

C.A. 91 v. a

The air as soon as there is light is filled with innumerable images to which the eye serves as a magnet.

C.A. 109 v. a

In youth acquire that which may requite you for the deprivations of old age; and if you are mindful that old age has wisdom for its food, you will so exert yourself in youth, that your old age will not lack sustenance.

C.A. 112 r. a

There is no result in nature without a cause; understand the cause and you will have no need of the experiment. C.A. 147 v. a

Experience is never at fault; it is only your judgment that is in error in promising itself such results from experience as are not caused by our experiments. For having given a beginning, what follows from it must necessarily be a natural development of such a beginning, unless it has been subject to a contrary influence, while, if it is affected by any contrary influence, the result which ought to follow from the aforesaid beginning will be found to partake of this contrary influence in a greater or less degree in proportion as the said influence is more or less powerful than the aforesaid beginning. C.A. 154 r. b

Experience is not at fault; it is only our judgment that is in error in promising itself from experience things which are not within her power.

Wrongly do men cry out against experience and with bitter reproaches accuse her of deceitfulness. Let experience alone, and rather turn your complaints against your own ignorance, which causes you to be so carried away by your vain and insensate desires as to expect from experience things which are not within her power!

Wrongly do men cry out against innocent experience, accusing her often of deceit and lying demonstrations! C.A. 154 r. c

O mathematicians, throw light on this error.

The spirit has no voice, for where there is voice there is a body, and where there is a body there is occupation of space which prevents the eye from seeing things situated beyond this space; consequently this body of itself fills the whole surrounding air, that is by its images.

C.A. 190 v. b

The body of the earth is of the nature of a fish, a grampus or sperm whale, because it draws water as its breath instead of air. C.A. 203 r. b

How the movements of the eye of the ray of the sun and of the mind are the swiftest that can be:

The sun so soon as ever it appears in the east instantly proceeds with its rays to the west; and these are made up of three incorporeal forces, namely radiance, heat, and the image of the shape which produces these.

The eye so soon as ever it is opened beholds all the stars of our hemisphere.

The mind passes in an instant from the east to the west; and all the great incorporeal things resemble these very closely in their speed.

C.A. 204 v. a

When you wish to produce a result by means of an instrument do not allow yourself to complicate it by introducing many subsidiary parts but follow the briefest way possible, and do not act as those do who when they do not know how to express a thing in its own proper vocabulary proceed by a method of circumlocution and with great prolixity and confusion.

C.A. 206 v. a

Two weaknesses leaning together create a strength. Therefore the half of the world leaning against the other half becomes firm.

C.A. 244 v. a

While I thought that I was learning how to live, I have been learning how to die.

C.A. 252 r. a

Every part of an element separated from its mass desires to return to it by the shortest way.

C.A. 273 r. b

Nothingness has no centre, and its boundaries are nothingness.

My opponent says that nothingness and a vacuum are one and the same thing, having indeed two separate names by which they are called, but not existing separately in nature.

The reply is that whenever there exists a vacuum there will also be the space which surrounds it, but nothingness exists apart from occupation of space; it follows that nothingness and a vacuum are not the same, for the one is divisible to infinity, and nothingness cannot be divided because nothing can be less than it is; and if you were to take part from it this part would be equal to the whole, and the whole to the part.

C.A. 289 v. b

Aristotle in the Third [Book] of the Ethics: man is worthy of praise and blame solely in respect of such actions as it is within his power to do or to abstain from.

C.A. 289 v. c

He who expects from experience what she does not possess takes leave of reason.

C.A. 299 r. b

For what reason do such animals as sow their seed sow with pleasure and the one who awaits receives with pleasure and brings forth with pain?

C.A. 320 v. b

Intellectual passion drives out sensuality.

C.A. 358 v. a

The knowledge of past time and of the position of the earth is the adornment and the food of human minds.

C.A. 373 v. a

Among the great things which are found among us the existence of Nothing is the greatest. This dwells in time, and stretches its limbs into the past and the future, and with these takes to itself all works that are past and those that are to come, both of nature and of the animals, and possesses nothing of the indivisible present. It does not however extend to the essence of anything.

C.A. 398 v. d

CORNELIUS CELSUS[1]

The chief good is wisdom: the chief evil is the suffering of the body. Seeing therefore that we are made up of two things, namely of soul and body, of which the first is the better and the inferior is the body, wisdom belongs to the better part and the chief evil belongs to the worse part and is the worst. The best thing in the soul is wisdom, and even so the worst thing in the body is pain. As therefore the chief evil is bodily pain, so wisdom is the chief good of the soul, that is of the wise man, and nothing else can be compared to it.

Tr. 3 a

The lover is drawn by the thing loved, as the sense is by that which it perceives, and it unites with it, and they become one and the same thing. The work is the first thing born of the union; if the thing that is loved be base, the lover becomes base. When the thing taken into union is in harmony with that which receives it, there follow rejoicing and pleasure and satisfaction. When the lover is united to that which is loved it finds rest there; when the burden is laid down there it finds rest. The thing is known with our intellect.

Tr. 9 a

[1] Cornelii Celsi de medicina liber incipit (libri VIII), Florentiae, 1478; Mediolani, 1481; Venice, 1493 and 1497.

As a well-spent day brings happy sleep, so life well used brings happy death.

Tr. 28 a

Where there is most power of feeling, there of martyrs is the greatest martyr.

Tr. 35 a

All our knowledge originates in our sensibilities.

Tr. 41 a

Science, knowledge of the things that are possible present and past; prescience, knowledge of the things which may come to pass.

Tr. 46 r.

Demetrius was wont to say that there was no difference between the words and speech of the unskilled and ignorant and the sounds and rumblings caused by the stomach being full of superfluous wind. This he said not without reason for as he held it did not in the least matter from what part of them the voice emanated, whether from the lower parts or the mouth, since the one and the other were of equal worth and importance.

Tr. 52 a

Nothing can be written as the result of new researches.

Tr. 53 a

To enjoy — to love a thing for its own sake and for no other reason.

Tr. 59 a

The senses are of the earth, the reason stands apart from them in contemplation.

Tr. 60 a

Life well spent is long.

In rivers, the water that you touch is the last of what has passed and the first of that which comes: so with time present.

Tr. 63 a

Every action must necessarily find expression in movement.

To know and to will are two operations of the human mind.

To discern to judge to reflect are actions of the human mind.

Our body is subject to heaven, and heaven is subject to the spirit.

Tr. 65 a

Many times one and the same thing is drawn by two violences, namely necessity and power.

Water falls in rain; the earth absorbs it from necessity of moisture; and the sun raises it up not from necessity but by its power.

Tr. 70 a

The soul can never be infected by the corruption of the body, but acts in the body like the wind which causes the sound of the organ, wherein if one of the pipes becomes spoiled no good effect can be produced because of its emptiness.

Tr. 71 a

If you kept your body in accordance with virtue your desires would not be of this world.

You grow in reputation like bread in the hands of children. B 3 v.

There cannot be any sound where there is no movement or percussion of the air. There cannot be any percussion of the air where there is no instrument. There cannot be any instrument without a body. This being so a spirit cannot have either sound or form or force, and if it should assume a body it cannot penetrate or enter where the doors are shut. And if any should say that through air being collected together and compressed a spirit may assume bodies of various shapes, and by such instrument may speak and move with force, my reply to this would be that where there are neither nerves nor bones there cannot be any force exerted in any movement made by imaginary spirits. Shun the precepts of those speculators whose arguments are not confirmed by experience.

B 4 v.

OF WHAT FORCE IS

Force I define as a spiritual power, incorporeal and invisible, which with brief life is produced in those bodies which as the result of accidental violence are brought out of their natural state and condition.

I have said spiritual because in this force there is an active, incorporeal life; and I call it invisible because the body in which it is created does not increase either in weight or in size; and of brief duration because it desires perpetually to subdue its cause, and when this is subdued it kills itself.

B 63 r.

One ought not to desire the impossible.

E 31 v.

THE CONFIGURATION OF THE ELEMENTS

Of the configuration of the elements and first against those who deny the opinion of Plato, saying that if these elements invest one another in the shapes which Plato attributed to them a vacuum would be occasioned between one and the other which is not true. I prove this here but first of all it is necessary to set forth certain conclusions.

It is not necessary for any of the elements which invest one another to be of equal size in all its extent as between the part that invests and that which is invested. We see that the sphere of the water is manifestly of different degrees of thickness from its surface to its base, and that it would not only cover the earth if it had the shape of a cube that is of eight angles as Plato would have it, but it covers the earth having innumerable angles of rocks covered by the water and various protuberances and hollows without creating any vacuum between the water and the earth. Moreover as regards the air which clothes the sphere of the water together with the mountains and valleys which rise about this sphere there is not left any vacuum between the earth and the air. So that whoever has said that a vacuum is there produced has spoken foolishly.

To Plato one would make answer that the surfaces of the figures that the elements would have according to him could not exist.

Every flexible and liquid element has of necessity its spherical surface. This is proved with the sphere of water but first must be set forth certain conceptions and conclusions. That thing is higher which is more remote from the centre of the world, and that is lower which is nearer this centre. Water does not move of itself unless it descends and in moving itself it descends. These four conceptions placed two by two serve me to prove that water that does not move of itself has its surface equidistant to the centre of the world, speaking not of drops or other small quantities that attract one another as the steel its filings, but of the great masses.

F 27 r.

Conception: Necessity wills that the corporeal agent be in contact with that which employs it.

F 36 v.

Observe the light and consider its beauty. Blink your eye and look at it. That which you see was not there at first, and that which was there is no more.

Who is it who makes it anew if the maker dies continually?

F 49 v.

The other proof that Plato gave to those of Delos is not geometrical, because it proceeds by instruments, the compass and the rule, and experience does not show it; but this is all mental and in consequence geometrical.

F 59 r.

Man has great power of speech, but the greater part thereof is empty and deceitful. The animals have little, but that little is useful and true;[1] and better is a small and certain thing than a great falsehood.

F 96 v.

You who speculate on the nature of things, I praise you not for knowing the processes which nature ordinarily effects of herself, but rejoice if so be that you know the issue of such things as your mind conceives.

G 47 r.

Words which fail to satisfy the ear of the listener always either fatigue or weary him; and you may often see a sign of this when such listeners are frequently yawning. Consequently when addressing men whose good opinion you desire, either cut short your speech when you see these evident signs of impatience, or else change the subject; for if you take any other course, then in place of the approbation you desire you will win dislike and ill-will.

And if you would see in what a man takes pleasure without hearing him speak, talk to him and change the subject of your discourse several times, and when it comes about that you see him stand fixedly without either yawning or knitting his brows or making any other movement, then be sure that the subject of which you are speaking is the one in which he takes pleasure.

G 49 r.

Every evil leaves a sorrow in the memory except the supreme evil, death, and this destroys memory itself together with life.

H 33 v.

Nothing is so much to be feared as a bad reputation. This bad reputation is caused by vices.

H 40 r.

[1] i.e. 'vero' (the reading adopted by Dr. Richter). MS. has 'verso'.

Though nature has given sensibility to pain to such living organisms as have the power of movement, — in order thereby to preserve the members which in this movement are liable to diminish and be destroyed, — the living organisms which have no power of movement do not have to encounter opposing objects, and plants consequently do not need to have a sensibility to pain, and so it comes about that if you break them they do not feel anguish in their members as do the animals.

H 60 [12] r.

OF THE SOUL

Movement of earth against earth pressing down upon it causes a slight movement of the parts struck.

Water struck by water creates circles at a great distance round the spot where it is struck; the voice in the air goes further, in fire further still; mind ranges over the universe but being finite it does not extend into infinity.

H 67 [19] r.

[Parallel of organism of nature and man]

The water which rises in the mountains is the blood which keeps the mountain in life. If one of its veins be open either internally or at the side, nature, which assists its organisms, abounding in increased desire to overcome the scarcity of moisture thus poured out is prodigal there in diligent aid, as also happens with the place at which a man has received a blow. For one sees then how as help comes the blood increases under the skin in the form of a swelling in order to open the infected part. Similarly life being severed at the topmost extremity (of the mountain) nature sends her fluid from its lowest foundations up to the greatest height of the severed passage, and as this is poured out there it does not leave it bereft of vital fluid down to the end of its life.

H 77 [29] r.

Every wrong shall be set right.

H 99 [44 v.] r.

Movement is the cause of all life.

H 141 [2 v.] r.

He who does not value life does not deserve it.

I 15 r.

Nature is full of infinite causes which were never set forth in experience.

I 18 r.

What is it that is much desired by men, but which they know not while possessing? It is sleep.

I 56 [8] r.

Wine is good, but water is preferable at table.

I 122 [74] v.

Science is the captain, practice the soldiers.

I 130 [82] r.

FLAX AND DEATH

Flax is dedicated to death and human corruption: to death by the lakes with nets for birds beasts and fishes; to corruption by the linen cloths in which the dead are wrapped when they are buried, for in these cloths they suffer corruption.

And moreover this flax does not become separated from its stalks until it commences to soften and become corrupt; and it is this which one should use to make garlands and adornments for funeral processions.

L 72 v.

Truth alone was the daughter of time.

M 58 v.

Small rooms or dwellings set the mind in the right path, large ones cause it to go astray.

MS. 2038 Bib. Nat. 16 r.

Just as eating contrary to the inclination is injurious to the health, so study without desire spoils the memory, and it retains nothing that it takes in.

MS. 2038 Bib. Nat. 34 r.

Call not that riches which may be lost; virtue is our true wealth, and the true reward of its possessor. It cannot be lost; it will not abandon us unless life itself first leaves us. As for property and material wealth, these you should ever hold in fear; full often they leave their possessor in ignominy, mocked at for having lost possession of them.

MS. 2038 Bib. Nat. 34 v.

The earth is moved from its position by the weight of a tiny bird resting upon it.

The surface of the sphere of the water is moved by a tiny drop of water falling upon it.

B.M. 19 r.

Every action done by nature is done in the shortest way. B.M. 85 v.

Where the descent is easier there the ascent is more difficult.

B.M. 120 r.

That which is termed nothingness is found only in time and speech. In time it is found between the past and the future and retains nothing of the present; in speech likewise when the things spoken of do not exist or are impossible.

In the presence of nature nothingness is not found: it has its associates among the things impossible whence for this reason it has no existence.

In the presence of time nothingness dwells between the past and the future and possesses nothing of the present; and in the presence of nature it finds its associates among things impossible, whence for this reason it is said that it has no existence. For where nothingness existed there would be a vacuum.

Amid the immensity of the things about us the existence of nothingness holds the first place, and its function extends over the things that have no existence, and its essence dwells in respect of time between past and future, and possesses nothing of the present. This nothingness has the part equal to the whole and the whole to the part, the divisible to the indivisible, and its power does not extend among the things of nature, for inasmuch as this abhors a vacuum this nothingness loses its essence because the end of one thing is the beginning of another.

It is possible to conceive everything that has substance as divisible into an infinite number of parts.

Amid the greatness of the things around us the existence of nothingness holds the first place, and its function extends among the things which have no existence, and its essence dwells as regards time between the past and the future, and possesses nothing of the present. This nothingness has the part equal to the whole and the whole to the part, the divisible to the indivisible, and it comes to the same amount whether we divide it or multiply it or add to it or subtract from it, as is shown by the arithmeticians in their tenth sign which represents this nothingness. And its power does not extend among the things of nature.

B.M. 131 r.

[*Of the end of the world*]

The watery element remaining pent up within the raised banks of the rivers and the shores of the sea, it will come to pass with the upheaval

of the earth that as the encircling air has to bind and circumscribe the complicated structure of the earth, its mass which was between the water and the fiery element will be left straitly compassed about and deprived of the necessary supply of water.

The rivers will remain without their waters; the fertile earth will put forth no more her budding branches; the fields will be decked no more with waving corn. All the animals will perish, failing to find fresh grass for fodder; and the ravening lions and wolves and other beasts which live by prey will lack sustenance; and it will come about after many desperate shifts that men will be forced to abandon their life and the human race will cease to be.

And in this way the fertile fruitful earth being deserted will be left arid and sterile, and through the pent up moisture of the water enclosed within its womb and by the activity of its nature it will follow in part its law of growth until having passed through the cold and rarefied air it will be forced to end its course in the element of fire. Then the surface of it will remain burnt to a cinder, and this will be the end of all terrestrial nature.

B.M. 155 V.

[*A disputation*]

Against. — Why nature did not ordain that one animal should not live by the death of another.

For. — Nature being capricious and taking pleasure in creating and producing a continuous succession of lives and forms because she knows that they serve to increase her terrestrial substance, is more ready and swift in creating than time is in destroying, and therefore she has ordained that many animals shall serve as food one for the other; and as this does not satisfy her desire she sends forth frequently certain noisome and pestilential vapours and continual plagues upon the vast accumulations and herds of animals and especially upon human beings who increase very rapidly because other animals do not feed upon them; and if the causes are taken away the results will cease.

Against. — Therefore this earth seeks to lose its life while desiring continual reproduction for the reason brought forth, and demonstrated to you. Effects often resemble their causes. The animals serve as a type of the life of the world.

For. — Behold now the hope and desire of going back to one's own country or returning to primal chaos, like that of the moth to the light,

of the man who with perpetual longing always looks forward with joy to each new spring and each new summer, and to the new months and the new years, deeming that the things he longs for are too slow in coming; and who does not perceive that he is longing for his own destruction. But this longing is in its quintessence the spirit of the elements, which finding itself imprisoned within the life of the human body desires continually to return to its source.

And I would have you to know that this same longing is in its quintessence inherent in nature, and that man is a type of the world.

B.M. 156 V.

Therefore the end of nothingness and the beginning of the line are in contact one with another, but they are not joined together, and in such contact is the point which divides the continuation of nothingness and the line.

It follows that the point is less than nothing, and if all the parts of nothingness are equal to one we may the more conclude that all the points also are equal to one single point and one point is equal to all.

And from this it follows that many points imagined in continuous contact do not constitute the line, and as a consequence many lines in continuous contact as regards their sides do not make a surface, nor do many surfaces in continuous contact make a body, because among us bodies are not formed of incorporeal things.

The point is that which has no centre because it is all centre, and nothing can be less.

The contact of the liquid with the solid is a surface common to the liquid and to the solid, and the lighter liquids with the heavier have the same.

All the points are equal to one and one to all.

Nothingness has a surface in common with a thing and the thing has a surface in common with nothingness, and the surface of a thing is not part of this thing. It follows that the surface of nothingness is not part of this nothingness; it must needs be therefore that a mere surface is the common boundary of two things that are in contact; thus the surface of water does not form part of the water nor consequently does it form part of the atmosphere, nor are any other bodies interposed between them. What is it therefore that divides the atmosphere from the water? It is necessary that there should be a common boundary which is neither air nor water but is without substance, because a body interposed

between two bodies prevents their contact, and this does not happen in water with air because they are in contact without the interposition of any medium.

Therefore they are joined together and you cannot raise up or move the air without the water, nor will you be able to raise up the flat thing from the other without drawing it back through the air. Therefore a surface is the common boundary of two bodies which are not continuous, and does not form part of either one or the other for if the surface formed part of it it would have divisible bulk, whereas however it is not divisible and nothingness divides these bodies the one from the other.

B.M. 159 v.

OF TIME AS A CONTINUOUS QUANTITY

Although time is numbered among continuous quantities yet through its being invisible and without substance it does not altogether fall under the category of geometrical terms, which are divided in figures and bodies of infinite variety, as may constantly be seen to be the case with things visible and things of substance; but it harmonises with these only as regards its first principles, namely as to the point and the line. The point as viewed in terms of time is to be compared with the instant, and the line resembles the length of a quantity of time. And just as points are the beginning and end of the said line so instants form the end and the beginning of a certain given space of time. And if a line be divisible to infinity it is not impossible for a space of time to be so divided. And if the divided parts of a line may bear a certain proportion one to another so also may the parts of time.

B.M. 173 v. and 190 v.

Given the cause nature produces the effect in the briefest manner that it can employ.

B.M. 174 v.

Write of the nature of time as distinct from its geometry.

B.M. 176 r.

DISCOURSE

Heat and cold proceed from the propinquity and remoteness of the sun.

Heat and cold produce the movement of the elements.

No element has of itself gravity or levity.

Gravity and levity without increase arise from the movement of the

element in itself in its rarefaction and condensation, as we see happen in the atmosphere in the creation of clouds by means of the moisture which is diffused through it.

Gravity and levity when increased proceed along a perpendicular line from one element to another. And these unforeseen events have as much more power as they have more of life, and as much more of life as they have more of movement.

The movement originates in the fact that what is thinner can neither resist nor support above it what is more dense.

Levity is born of gravity and gravity of levity; repaying in the same instant the boon of their creation they grow the more in power as they grow in life and have the more life in proportion as they have more movement; in the same instant also they destroy one another in the common vendetta of their death.

For so it is proved: levity is not created unless it is in conjunction with gravity, nor is gravity produced unless it is continued in levity. But the levity has no existence unless it is underneath gravity, and gravity is as nothing unless it is above levity. And so it is with the elements. If for example a quantity of air lay beneath water then it follows that the water immediately acquires gravity; not that it is changed from its first condition but because it does not meet with the due amount of resistance; it therefore descends into the position occupied by the air which was beneath it and the air fills up the vacuum which the gravity so created has left in it.

B.M. 204 r.

Every continuous quantity is infinitely divisible; therefore the division of this quantity will never result in a point which is given as the extremity of a line. It follows that the breadth and depth of the natural line is divisible to infinity.

It is asked whether all the infinites are equal or whether they are greater the one than the other. The answer is that every infinite is eternal and eternal things are of equal permanence but not of equal length of existence. For that which functioned first commenced to divide and has passed a longer existence, but the periods to come are equal.

B.M. 204 v.

No element has in itself gravity or levity unless it moves. The earth is in contact with the water and with the air and has of itself neither

gravity nor levity. It has no consciousness of the water or air which surrounds it except by accident which arises from their movement. And this we learn from the leaves of plants which grow upon the earth when it is in contact with water or air, for they do not bend except by the movement of the air or water.

From the foregoing we should say that gravity is an incident created by the movement of the lower elements in the higher.

Levity is an incident created when the thinner element is drawn beneath the less thin which then moves being unable to resist and then acquires weight this being created so soon as the element lacks the power of resistance; which resistance being subdued by weight it does not change without change of substance; and in changing it acquires the name of levity.

Levity is not produced except together with gravity, nor gravity without levity: this may be produced: for let air be suspended under water by blowing through a pipe, then this air will acquire levity from being beneath the water and the water will acquire gravity from having beneath it the air which is a body thinner and lighter than itself.

Therefore levity is born of weight and weight of lightness, and they give birth one to another at the same time repaying the boon of their existence, and at the same instant they destroy one another as the avengers of their death.

Levity and gravity are caused by immediate movement.

Movement is created by heat and cold.

Movement is an incident created by inequality of weight and force.

The atmosphere has not of itself a natural position and always closes up over a body that is thicker than itself, never over the lighter when it is in contact with it except by violence.

The movement of the elements arises from the sun.

The heat of the universe is produced by the sun.

The light and heat of the universe come from the sun and its cold and darkness from the withdrawal of the sun.

Every movement of the elements arises from heat and cold.

Gravity and levity are created in the elements.

B.M. 205 r.

The earth is in contact with the water and the air, and acquires as much weight from the water as from the air; and this is nothing unless they have movement.

This we may learn from the leaves of plants born in the depths of the water which lies upon the meadows, and the leaves and branches of the trees, and similarly from the fact of plants born in the bed of the waters not bending down it is manifest that the air and the water do not give their weight to the earth.

B.M. 266 v.

EXAMPLE OF THE CENTRE OF THE WORLD

Suppose the earth to be drawn to the position of the moon together with the water, and that the element of the air fills with itself the vacuum in the air which the earth in separating has left of itself, and that from the air there falls a vase full of air, it is certain that this vase after many wavering movements, that is falling and reflex, will come to a stop at about the centre of the elements. And the centre of the elements will remain in the air that is within the vase and it will not touch the vase. Or suppose the earth hollowed out like a ball full of wind, you will then be certain that this centre is not in the earth, but in the air clothed by the earth.

B.M. 267 r.

Why does the eye see a thing more clearly in dreams than the imagination when awake?

B.M. 278 v.

Wisdom is the daughter of experience, which experience . . .

Forster III. 14 r.

And this man excels in folly in that he continually stints himself in order that he may not want, and his life slips away while he is still looking forward to enjoying the wealth which by extreme toil he has acquired.

Forster III. 17 v.

Here nature seems in many or for many animals to have been rather a cruel step-mother than a mother, and for some not a step-mother but a compassionate mother.

Forster III. 20 v.

I obey thee, O Lord, first because of the love which I ought reasonably to bear thee; secondly, because thou knowest how to shorten or prolong the lives of men.

Forster III. 29 r.

Shun those studies in which the work that results dies with the worker.

Forster III. 55 r.

Lo some who can call themselves nothing more than a passage for food, producers of dung, fillers up of privies, for of them nothing else appears in the world, nor is there any virtue in their work, for nothing of them remains but full privies.

Forster III. 74 v.

And thou, man, who by these my labours dost look upon the marvellous works of nature, if thou judgest it to be an atrocious act to destroy the same, reflect that it is an infinitely atrocious act to take away the life of man. For thou shouldst be mindful that though what is thus compounded seem to thee of marvellous subtlety, it is as nothing compared with the soul that dwells within this structure; and in truth, whatever this may be, it is a divine thing which suffers it thus to dwell within its handiwork at its good pleasure, and wills not that thy rage or malice should destroy such a life, since in truth he who values it not does not deserve it.

For we part from the body with extreme reluctance, and I indeed believe that its grief and lamentation are not without cause.

Fogli A. 2 r.

The idea or the faculty of imagination is both rudder and bridle to the senses, inasmuch as the thing imagined moves the sense.

Pre-imagining is the imagining of things that are to be.

Post-imagining is the imagining of things that are past.

Fogli B. 2 v.

[*Of new necessities*][1]

Neither promise yourself things nor do things if you see that when deprived of them they will cause you material suffering.

Fogli B 21 v.

OF NECROMANCY

But of all human discourses that must be considered as most foolish which affirms a belief in necromancy, which is the sister of alchemy, the producer of simple and natural things, but is so much the more worthy of blame than alchemy, because it never gives birth to anything whatever except to things like itself, that is to say lies; and this is not the case with alchemy, which works by the simple products of nature, but whose function cannot be exercised by nature herself, because there are in her no organic instruments with which she might be able to do the work

[1] The phrase is one used by Benjamin Jowett with regard to smoking. His advice was: 'Do not set up for yourself any new necessities.'

which man performs with his hands, by the use of which he has made glass, etc. But this necromancy, an ensign or flying banner, blown by the wind, is the guide of the foolish multitude, which is a continual witness by its clamour to the limitless effects of such an art. And they have filled whole books in affirming that enchantments and spirits can work and speak without tongues, and can speak without any organic instrument, — without which speech is impossible, — and can carry the heaviest weights, and bring tempests and rain, and that men can be changed into cats and wolves and other beasts, although those first become beasts who affirm such things.

And undoubtedly if this necromancy did exist, as is believed by shallow minds, there is nothing on earth that would have so much power either to harm or to benefit man; if it were true, that is, that by such an art one had the power to disturb the tranquil clearness of the air, and transform it into the hue of night, to create coruscations and tempests with dreadful thunder-claps and lightning-flashes rushing through the darkness, and with impetuous storms to overthrow high buildings and uproot forests, and with these to encounter armies and break and overthrow them, and — more important even than this — to make the devastating tempests, and thereby rob the husbandmen of the reward of their labours. For what method of warfare can there be which can inflict such damage upon the enemy as the exercise of the power to deprive him of his crops? What naval combat could there be which should compare with that which he would wage who has command of the winds and can create ruinous tempests that would submerge every fleet whatsoever? In truth, whoever has control of such irresistible forces will be lord over all nations, and no human skill will be able to resist his destructive power. The buried treasures, the jewels that lie in the body of the earth will all become manifest to him; no lock, no fortress, however impregnable, will avail to save anyone against the will of such a necromancer. He will cause himself to be carried through the air from East to West, and through all the uttermost parts of the universe. But why do I thus go on adding instance to instance? What is there which could not be brought to pass by a mechanician such as this? Almost nothing, except the escaping from death.

We have therefore ascertained in part the mischief and the usefulness that belong to such an art if it is real; and if it is real why has it

not remained among men who desire so much, not having regard to any deity, merely because there are an infinite number of persons who in order to gratify one of their appetites would destroy God and the whole universe?

If then it has never remained among men, although so necessary to them, it never existed, and never can exist, as follows from the definition of a spirit, which is invisible and incorporeal, for within the elements there are no incorporeal things, because where there is not body there is a vacuum, and the vacuum does not exist within the elements, because it would be instantly filled up by the element.

Fogli B 31 v.

Therefore O students study mathematics and do not build without foundations.

Quaderni I 7 r.

Mental things which have not passed through the understanding are vain and give birth to no truth other than what is harmful. And because such discourses spring from poverty of intellect those who make them are always poor, and if they have been born rich they shall die poor in their old age. For nature as it would seem takes vengeance on such as would work miracles and they come to have less than other men who are more quiet. And those who wish to grow rich in a day shall live a long time in great poverty, as happens and will to all eternity happen to the alchemists, the would-be creators of gold and silver, and to the engineers who think to make dead water stir itself into life with perpetual motion, and to those supreme fools, the necromancer and the enchanter.

Quaderni I 13 v.

[*The certainty of mathematics*]

He who blames the supreme certainty of mathematics feeds on confusion, and will never impose silence upon the contradictions of the sophistical sciences, which occasion a perpetual clamour.

The abbreviators of works do injury to knowledge and to love, for love of anything is the offspring of knowledge, love being more fervent in proportion as knowledge is more certain; and this certainty springs from a thorough knowledge of all those parts which united compose the whole of that thing which ought to be loved.

Of what use, pray, is he who in order to abridge the part of the

things of which he professes to give complete information leaves out the greater part of the matters of which the whole is composed?

True it is that impatience the mother of folly is she who praises brevity; as though such folk had not a span of life that would suffice to acquire complete knowledge of one particular subject such as the human body. And then they think to comprehend the mind of God which embraces the whole universe, weighing and dissecting it as though they were making an anatomy. O human stupidity! Do you not perceive that you have spent your whole life with yourself and yet are not aware of that which you have most in evidence, and that is your own foolishness? And so with the crowd of sophists you think to deceive yourself and others, despising the mathematical sciences in which is contained true information about the subjects of which they treat! Or you would fain range among the miracles and give your views upon those subjects which the human mind is incapable of comprehending and which cannot be demonstrated by any natural instance. And it seems to you that you have performed miracles when you have spoiled the work of some ingenious mind, and you do not perceive that you are falling into the same error as does he who strips a tree of its adornment of branches laden with leaves intermingled with fragrant flowers or fruits, in order to demonstrate the suitability of the tree for making planks. Even as did Justinus, maker of an epitome of the histories of Trogus Pompeius, who had written an elaborate account of all the great deeds of his ancestors which lent themselves to picturesque description, for by so doing he composed a bald work fit only for such impatient minds as conceive themselves to be wasting time when they spend it usefully in study of the works of nature and of human things.

Let such as these remain in the company of the beasts, and let their courtiers be dogs and other animals eager for prey and let them keep company with them; ever pursuing whatever takes flight from them they follow after the inoffensive animals who in the season of the snow drifts are impelled by hunger to approach your doors to beg alms from you as from a guardian.

If you are as you have described yourself the king of the animals — it would be better for you to call yourself king of the beasts since you are the greatest of them all! — why do you not help them so that they may presently be able to give you their young in order to gratify your palate, for the sake of which you have tried to make yourself a tomb for

all the animals? Even more I might say if to speak the entire truth were permitted me.

But do not let us quit this subject without referring to one supreme form of wickedness which hardly exists among the animals, among whom are none that devour their own species except for lack of reason (for there are insane among them as among human beings though not in such great numbers). Nor does this happen except among the voracious animals as in the lion species and among leopards, panthers, lynxes, cats and creatures like these, which sometimes eat their young. But not only do you eat your children, but you eat father, mother, brothers and friends; and this even not sufficing you you make raids on foreign islands and capture men of other races and then after mutilating them in a shameful manner you fatten them up and cram them down your gullet. Say does not nature bring forth a sufficiency of simple things to produce satiety? Or if you cannot content yourself with simple things can you not by blending these together make an infinite number of compounds as did Platina and other authors who have written for epicures?

And if any be found virtuous and good drive them not away from you but do them honour lest they flee from you and take refuge in hermitages and caves or other solitary places in order to escape from your deceits. If any such be found pay him reverence, for as these are as gods upon the earth they deserve statues, images and honours. But I would impress upon you that their images are not to be eaten by you, as happens in a certain district of India; for there, when in the judgment of the priests these images have worked some miracle, they cut them in pieces being of wood and distribute them to all the people of the locality — not without payment.

And each of them then grates his portion very fine and spreads it over the first food he eats; and so they consider that symbolically by faith they have eaten their saint, and they believe that he will then guard them from all dangers. What think you Man! of your species? Are you as wise as you set yourself up to be? Are acts such as these things that men should do, Justinus?

Quaderni II 14 r.

Let no one read me who is not a mathematician in my beginnings.

Quaderni IV 14 v.

Every action of nature is made along the shortest possible way.

Quaderni IV 16 r.

Thou, O God, dost sell unto us all good things at the price of labour.[1]

Quaderni v 24 r.

JOHANNES ANTONIUS DI JOHANNES AMBROSIUS DE BOLATE[2]

He who suffers time to slip away and does not grow in virtue the more one thinks about him the sadder one becomes.

No man has a capacity for virtue who sacrifices honour for gain. Fortune is powerless to help one who does not exert himself. That man becomes happy who follows Christ.

There is no perfect gift without great suffering. Our triumphs and our pomps pass away; gluttony and sloth and enervating luxury have banished every virtue from the world; so that as it were wandering from its course our nature is subdued by habit. Now and henceforth it is meet that you cure yourself of laziness. The Master has said that sitting on down or lying under the quilts will not bring thee to fame.

He who without it has frittered life away leaves no more trace of himself upon the earth than smoke does in the air or the foam on the water.

Windsor: Drawings 12349 v.

Nothing grows in a spot where there is neither sentient, fibrous nor rational life. The feathers grow upon birds and change every year; hair grows upon animals and changes every year except a part such as the hair of the beard in lions and cats and creatures like these. The grass grows in the fields, the leaves upon the trees, and every year these are renewed in great part. So then we may say that the earth has a spirit of growth, and that its flesh is the soil; its bones are the successive strata of the rocks which form the mountains; its cartilage is the tufa stone; its blood the springs of its waters. The lake of blood that lies about the heart is the ocean. Its breathing is by the increase and decrease of the blood in its pulses, and even so in the earth is the ebb and flow of the

[1] MS. 'Idio ci vende tutti li beni per prezzo di faticha.' Above it is the word 'oratio' and 'tu' to the right of it is perhaps connected by a stroke with 'idio'. 'Oratio' may either be interpreted as meaning 'a prayer' or it may be a reference to the poet Horace. The latter interpretation receives some support from the fact of the similarity of thought between the sentence which follows and a passage in the *Satires* of Horace, Bk. I, 9, 58-9:

'Nil sine magno
Vita labore dedit mortalibus'.

[2] The sentence that commences 'The Master has said' seems to suggest that these are notes of Leonardo's precepts by a pupil, who apparently began by writing his own name.

sea. And the vital heat of the world is fire which is spread throughout the earth; and the dwelling place of its creative spirit is in the fires, which in divers parts of the earth are breathed out in baths and sulphur mines, and in volcanoes, such as Mount Etna in Sicily, and in many other places.

Leic. 34 r.

Falsehood is so utterly vile that though it should praise the great works of God it offends against His divinity. Truth is of such excellence that if it praise the meanest things they become ennobled.

Without doubt truth stands to falsehood in the relation of light to darkness, and truth is in itself of such excellence that even when it treats of humble and lowly matters it yet immeasurably outweighs the sophistries and falsehoods which are spread out over great and high-sounding discourses; for though we have set up falsehood as a fifth element in our mental state it yet remains that the truth of things is the chief food of all finer intellects — though not indeed of wandering wits.

But you who live in dreams, the specious reasonings, the feints which *palla* players might use, if only they treat of things vast and uncertain, please you more than do the things which are sure and natural and of no such high pretension.

Sul Volo 12 [11] r.

II

Aphorisms

'Iron rusts from disuse, stagnant water loses its purity and in cold weather becomes frozen; even so does inaction sap the vigour of the mind.'

Whoever in discussion adduces authority uses not intellect but rather memory.

Good literature proceeds from men of natural probity, and since one ought rather to praise the inception than the result, you should give greater praise to a man of probity unskilled in letters than to one skilled in letters but devoid of probity.

C.A. 76 r. a

As courage endangers life even so fear preserves it.

Threats only serve as weapons to the threatened.

Who walks rightly seldom falls.

You do ill if you praise but worse if you censure what you do not rightly understand.

C.A. 76 v. a

To devise is the work of the master, to execute the act of the servant.

He who has most possessions should have the greatest fear of loss.

C.A. 109 v. a

The natural desire of good men is knowledge.

C.A. 119 v. a

Aristotle says that everything desires to keep its own nature.

C.A. 123 r. a

A thing that moves acquires as much space as it loses.

C.A. 152 v. a

Who goes not ever in fear sustains many injuries and often repents.

C.A. 170 r. b

The acquisition of any knowledge whatever is always useful to the intellect, because it will be able to banish the useless things and retain those which are good. For nothing can be either loved or hated unless it is first known.

C.A. 226 v. b

Inequality is the cause of all local movements.

There is no rest without equality.

C.A. 288 v. a

The words freeze in your mouth and you will make ice on Mount Etna.

Iron rusts from disuse; stagnant water loses its purity and in cold weather becomes frozen; even so does inaction sap the vigour of the mind. C.A. 289 v. c

Happy is that estate which is seen by the eye of its lord.

Love conquers everything.

This by experience is proved, that he who never puts his trust in any man will never be deceived. C.A. 344 r. b

The instruments of swindlers are the seed of human revilings against the gods. C.A. 358 v. a

ANAXAGORAS

Everything comes from everything, and everything is made out of everything, and everything returns into everything, because whatever exists in the elements is made out of these elements. C.A. 385 v. c

Savage is he who saves himself. Tr. 1 a

Folly is the buckler of shame as importunity is of poverty. Tr. 52 a

[*Sketch*]

Truth brings it here to pass that falsehood afflicts the lying tongues. F cover 2 r.

The memory of benefits is frail as against ingratitude.

Reprove a friend in secret but praise him before others.

He who walks in fear of dangers will not perish in consequence thereof.

Lie not about the past. H 16 v.

[*Concerning fame*]

Nothing is more to be feared than ill fame.

Toil flees away bearing in its arms fame almost hidden. H 17 v.

Lust is the cause of generation.

Appetite is the stay of life.

Fear or timidity is the prolongation of life.

Deceit is the preservation of the instrument. H 32 r.

Moderation curbs all the vices.

The ermine would rather die than soil itself.

OF FORESIGHT

The cock does not crow until he has flapped his wings three times.

The parrot passing from branch to branch never puts his foot where he has not first fixed his beak.

Vows begin when hope dies.

Movement tends towards the centre of gravity. H 48 v.

[*With drawings*]

To take away pain.

To know better the direction of the winds.

From a light thing there proceeds a great ruin. H 100 [43 v.] r.

It is by testing that we discern fine gold.

As is the mould so will the cast be. H 100 [43 r.] v.

He who strips the wall bare on him will it fall.

He who cuts the tree down on him will it take vengeance in its fall.

Let the traitor avoid death: other punishments if he undergo them do not mark him. H 118 [25 v.] r.

Ask counsel of him who governs himself well.

Justice requires power, intelligence and will. It resembles the queen bee.

He who neglects to punish evil sanctions the doing thereof.

He who takes the snake by the tail is afterwards bitten by it.

He who digs the pit upon him will it fall in ruin. H 118 [25 r.] v.

Whoso curbs not lustful desires puts himself on a level with the beasts.

You can have neither a greater nor a less dominion than that over yourself.

He who thinks little makes many mistakes.

It is easier to resist at the beginning than at the end.

No counsel is more trustworthy than that which is given upon ships that are in peril.

Let him expect disaster who shapes his course on a young man's counsel. H 119 [24 r.] v.

Think well to the end, consider the end first. H 139 [4 r.] v.

[*Fear*]
Fear springs to life more quickly than anything else. L 90 v.

He who injures others does not safeguard himself. M 4 v.

Give to your master the example of the captain, for it is not he who conquers but the soldiers by means of his counsel and yet he deserves the reward. Forster II 15 v.

It is as great an error to speak well of a worthless man as to speak ill of a good man. Forster II 41 v.

Necessity is the mistress and guardian of nature.
Necessity is the theme and artificer of nature — the bridle, the law, and the theme. Forster III 43 v.

Poor is the pupil who does not surpass his master. Forster III 66 v.

[*Sketch — head of old woman*]
In life beauty perishes and does not endure.[1] Forster III 72 r.

Dust makes damage. Quaderni III 10 v.

The heavy cannot be created without it being joined with the light and together they destroy each other. Quaderni III 12 r.

[1] The text of this sentence *Cosa bella mortal passa e non dura* as has been pointed out by Sir Eric Maclagan in a letter in *The Times Literary Supplement* (March 8th, 1923) occurs as a line in a sonnet of Petrarch: 'Chi vuol veder quantunque può Natura', No. CXC, line 8.
In the former edition of *Leonardo's Notebooks* I translated this sentence as 'in life beauty perishes, not in art', having in my reading of the text followed Dr. Richter in supposing the last word to be 'dart' for 'd'arte'. A further examination of a photograph of the page kindly supplied to me by Sir Eric Maclagan has convinced me of my error.
It is in the erroneous form *cosa bella mortal passa e non d'arte* which originated merely in an error of transcription that the sentence occurs on the title-page of d'Annunzio's tragedy *La Gioconda*.

[*Studies of emblems with mottoes*]
Obstacles cannot bend me.
Every obstacle yields to effort.
Not to leave the furrow.
He who fixes his course by a star changes not.

Windsor: Drawings 12282 r.

[*Drawings of same*]
Persistent effort.
Predetermined effort.
He is not turned who is fixed to such a star.

Windsor: Drawings 12701

May I be deprived of movement ere I weary of being useful.
Movement will fail sooner than usefulness.
Death rather than weariness.
I never weary in being useful. I am not tired of serving others.
I weary not in welldoing is a motto for carnival.
Without fatigue.
No labour suffices to tire me.

Hands into which fall like snow ducats and precious stones, these never tire of serving, but such service is only for its usefulness and not for our own advantage.

I never weary of being useful.
Naturally nature has so fashioned me.

Windsor: Drawings 12700 r.

He who wishes to become rich in a day is hanged in a year.

Windsor: Drawings 12351 r.

III

Anatomy

'I reveal to men the origin of their second—first or perhaps second—cause of existence.'

'Would that it might please our Creator that I were able to reveal the nature of man and his customs even as I describe his figure.'

[*Precepts for the study of the foot*]

You will make these two feet with the same contours turned in the same direction, and do not pay any regard to the fact that they remain the one right and the other left, because by making them so they will be easier to understand.

First you will make all these bones separated the one from the other, arranged in such a way that each part of each bone may be seen, or may be turned towards the side of that bone from which it is separated, and to which it should be reunited when you join up all the bones of these feet together in their first state.

And this demonstration is made in order to be better able to recognise the true shape of each bone in itself; and you will do the same with each demonstration of each limb in whatever direction it may be turned.

Fogli A I r.

[*Method for the study of the arm and the forearm*]

You will first have these bones sawn lengthwise and then across, so that one can see where the bones are thick or thin; then represent them whole and disjoined, as here above, but from four aspects in order that one can understand their true shape; then proceed to clothe them by degrees with their nerves, veins and muscles.

[*Method for the study of the parts of the human body*]

The true knowledge of the shape of any body will be arrived at by seeing it from different aspects. Consequently in order to convey a notion of the true shape of any limb of man who ranks among the animals as first of the beasts I will observe the aforesaid rule, making four demonstrations for the four sides of each limb, and for the bones I will make five, cutting them in half and showing the hollow of each of them, one being full of marrow the other spongy or empty or solid.

[*Of the bones of the arm*]

The arm, which has the two bones that interpose between the hand and the elbow, will be somewhat shorter when the palm of the hand is turned towards the ground than when it is turned towards the sky, if the man is standing on his feet with his arm extended. And this occurs because these two bones, in turning the palm of the hand towards the

ground, come to intersect in such a way that that which proceeds from the right side of the elbow goes towards the left side of the palm of the hand, and that which proceeds from the left side of the elbow ends on the right side of the palm of this hand.

The arm is composed of thirty pieces of bone, because there are three in the arm itself and twenty seven in the hand.

Fogli A 1 v.

[*Of the attachment of the muscles*]

The above-mentioned muscles are not firm except at the extremities of their receptacles and at the extremities of their tendons; and this the Master has done in order that the muscles may be free and ready to be able to grow thicker or shorter or finer or longer according to the necessity of the thing which they move.

Fogli A 2 r.

Commence your anatomy with the head and finish it with the soles of the feet.

[*Voice production — mechanism of*]

Rule to see how the sound of the voice is produced in the front of the trachea. This will be understood by separating this trachea together with the lung of the man, and if this lung be filled with air and then closed rapidly one will be able immediately to see in what way the pipe called the trachea produces this sound; and this can be perceived and heard well in the neck of a swan or a goose which often continues to sing after it is dead.

One cannot swallow and breathe or make a sound at the same time.

One cannot breathe by the nose and by the mouth at the same time; and this is shown if one should attempt to play a whistle or flute with the nose and another with the mouth at the same time.

WHY THE VOICE GROWS THIN IN THE OLD

The voice grows thin in the old because all the passages of the trachea become restricted as do the other intestines.

Fogli A 3 r.

The pieces of the bone of which a man's foot is composed number twenty seven, taking into account the two which are beneath the base of the great toe of the foot.

Fogli A 3 v.

STUDIES OF DELTOID MUSCLE

Royal Library, Windsor

THE NATURE OF THE VEINS

The origin of the sea is the contrary to that of the blood, for the sea receives within itself all the rivers, which are entirely caused by the aqueous vapours that have ascended up into the air; while the sea of the blood is the source of all the veins.

OF THE NUMBER OF THE VEINS

The vein is one whole, which is divided into as many main branches as there are principal places which it has to nourish, and these branches are subdivided in an infinite number.

[*Movements of the neck*]

The neck has four movements, of which the first consists of raising the second of lowering the face, the third of turning right or left, the fourth of bending the head right or left. [. . .] are mixed movements, namely raising or lowering the face with an ear near to a shoulder, and similarly raising or lowering the face after turning it towards one of the shoulders; also raising or lowering the face after turning it to one of the shoulders while keeping one eye lower or higher than the other, and this is called separated movement.

And to these movements should be assigned the cords and muscles which are the cause of these movements, and consequently, if a man should be found lacking in power to make one of these movements as a result of some wound, one can discern with certainty which cord or muscle is impeded.

Fogli A 4 r.

[*The true conception of figures*]

One possesses a true conception of all figures when one knows their breadth, length and depth; if therefore I observe the same in the figure of the man I shall give a true conception of it in the opinion of everyone of sound intelligence.

Explain these words for they are confused.

[*Arrangement of muscles of neck and thorax*]

Make it twice as much larger with a corresponding thickness of ribs and muscles, and it will be easier to understand.

Again this figure would be confused unless you first of all made at

least three demonstrations before this with similar threads; demonstrations of which the first should be merely of the bones, then follow with the muscles which start in the breast above the ribs, and finally the muscles that start from the thorax together with the ribs and last of all that above.

Make the ribs so thin that in the final demonstration made with the threads the position of the shoulder-blade may be visible.

[*Precepts for the study of the muscles*]

Before you represent the muscles make, in place of these, threads which may serve to show the positions of these muscles, which should abut with their extremities in the centre of the attachment of the muscles above their bones. And this will supply a speedier conception when you wish to represent all the muscles one above the other. And if you make it in any other way your representation will be confused.

Fogli A 4 v.

[*Precepts for the study of the cervical vertebrae*]

These three vertebrae should be shown from three aspects as has been done with three from the backbone.

The vertebrae of the neck are seven of which the first above and the second differ from the other five.

You should make these bones of the neck from three aspects united and from three separated; and so you will afterwards make them from two other aspects, namely seen from below and from above, and in this way you will give the true conception of their shapes, which neither ancient nor modern writers have ever been able to give without an infinitely tedious and confused prolixity of writing and of time.

But by this very rapid method of representing from different aspects a complete and accurate conception will result, and as regards this benefit which I give to posterity I teach the method of reprinting it in order, and I beseech you who come after me, not to let avarice constrain you to make the prints in . . .

Fogli A 8 v.

The act of procreation and the members employed therein are so repulsive, that if it were not for the beauty of the faces and the adornments of the actors and the pent-up impulse, nature would lose the human species.

[*Movement and force of animals subject to mechanical laws*]

Arrange it so that the book of the elements of mechanics with examples shall precede the demonstration of the movement and force of man and of the other animals, and by means of these you will be able to prove all your propositions.

[*Anatomy of hand*]

Describe how many membranes intervene between the skin and the bones of the hand.

[*Precepts for study of muscles of hand*]

These muscles of the hand may be made first of threads and then according to their true shape.

And they are the muscles that move all the palm of the hand.

When you have represented the bones of the hand and you wish to represent above this the muscles which are joined with these bones make threads in place of muscles. I say threads and not lines in order to know what muscle passes below or above the other muscle, which thing cannot be shown with simple lines; and after doing this make another hand afterwards at the side of it where there may be the true shape of these muscles as is shown here above.

Fogli A 10 r.

REPRESENTATION OF THE HAND

The first demonstration of the hand will be made of the bones alone. The second of the ligaments and various chains of nerves that bind them together. The third will be of the muscles which spring up upon these bones. The fourth will be of the first tendons which rest upon these muscles and go to supply movement to the tips of the fingers. The fifth will be that which shows the second set of tendons which move all the fingers and end at the last but one of the bones of the fingers. The sixth will be that which will show the nerves that impart sensation to the fingers of the hand. The seventh will be that which will show the veins and arteries that nourish and invigorate the fingers. The eighth and last will be the hand clothed with skin, and this will be shown for an old man, a young man and a child, and for each there should be given the measurement of the length, thickness and breadth of each of its parts.

Fogli A 10 v.

[*Precepts for the study of the foot*]

Make a demonstration of this foot with the simple bones; then leaving the membrane that clothes them make a simple demonstration of the nerves; and then over the same bones make one of tendons, and then one of veins and artery together. And finally a single one to contain artery, veins, nerves, tendons, muscles and bones.

The muscles that move the toes at their points, both below and above, all appear in the leg between the knee and the joint of the foot; and those that move the whole toe upwards and downwards appear on the upper and lower side of the foot; and as the hand works with its arm so does the foot with the leg.

Fogli A II r.

[*Precepts for the study of the foot*]

Make a demonstration of these feet without the membrane that clothes the bones, which membrane takes possession of these bones, interposing itself between these bones and the muscles and tendons that move them; and by this way you will be able to show under which tendons, nerves, veins or muscle are the joints of the bones.

[*Representation of the limbs in action*]

After the demonstration of all the parts of the limbs of man and of the other animals you will represent the proper method of action of these limbs, that is in rising after lying down, in moving, running and jumping in various attitudes, in lifting and carrying heavy weights, in throwing things to a distance and in swimming, and in every act you will show which limbs and which muscles are the causes of the said actions, and especially in the play of the arms.

REASON WHY TWO MUSCLES ARE JOINED TOGETHER

It often occurs that two muscles are joined together although they have to serve two limbs; and this has been done so that if one muscle were incapacitated by some injury the other muscle in part supplied the place of that which was lacking.

Fogli A II v.

[*Precepts for the study of the bones of the foot*]

You will represent these bones of the feet all equally spread out, in order that their number and shape may be distinctly understood. And this difference you will represent from four aspects in order that the

true shape of these bones in all their aspects may be more accurately known.

Make the bones of the foot somewhat separated one from another in such a way that one may readily distinguish one from another, and this will be the means of imparting the knowledge of the number of the bones of the feet and of their shape.

At the end of every representation of the feet you will give the measure of the thickness and length of each of the bones and its position.

The aspects of the foot are six, namely: below, above, within, outside, behind and before; and to these is added the six demonstrations of the separated bones between them; and there are those of the bones sawn lengthwise in two ways, that is, sawn through the side and straight so as to show all the thickness of the bones.

Fogli A 12 r.

[*Motor muscles of hands and wings*]

No movement either of the hand or the fingers is produced by the muscles above the elbow; and so it is with birds and it is for this reason that they are so powerful because all the muscles which lower the wings spring from the breast and these have in themselves a greater weight than that of all the rest of the bird.

Fogli A 12 v.

[*Insertion of muscles*]

You will make a second representation of the bones in which you will show how the muscles are fastened upon the bones.

Fogli A 13 r.

[*Precepts for the study of the bones and the muscles of man and horse*]

Note where the lowest parts of the muscles of the shoulder *a b c d* are fixed, and which are those that are attached above the bone called humerus, and which are attached above the other muscles.

Make for each bone separated by itself its muscles, that is the muscles which grow upon it.

Show all the causes of the movement of the skin, flesh and muscles of a face, and whether the muscles derive their movement from the nerves that come from the brain or no.

And do this first of all with the horse which has big muscles and parts very distinct.

See whether the muscle that raises the horse's nostrils is the same as is found here in the man at *f*, which comes out of the hole in the bone *f*.

[Arrangements of vessels and nerves of fingers]

Have you seen the diligence of nature in having situated the nerves, arteries and veins not in the centre but in the sides of the fingers so that they are not in any way pierced or cut by the movements of the fingers?

[Nerves of sensibility and movement of the fingers and their independence of function]

See if you understand that this sense is employed by the player of an organ, and that the mind at such time waits on the sense of hearing.

Fogli A 13 v.

[Necessary to represent and to describe]

And you who think to reveal the figure of man in words, with his limbs arranged in all their different attitudes, banish the idea from you, for the more minute your description the more you will confuse the mind of the reader and the more you will lead him away from the knowledge of the thing described. It is necessary therefore for you to represent and describe.

Should the actual thing being in relief seem to you to be more recognisable than what is here drawn, which impression springs from the fact of your being able to see the object from different aspects, you must understand that in this representation of mine the same result will be obtained from the same aspects; and therefore no part of these limbs will be hidden from you.

[Precepts for study of muscles of shoulder]

Describe each muscle, what finger it serves and what limb; represent it therefore simply, without any impediment from any other muscle that is placed over them, and in this way you will afterwards be able to recognise the parts which are injured.

You will never know the shape of the shoulder without this rule.

Write how each muscle can become extended or contracted or made thinner or thicker, and which is more or less powerful.

Represent here always together the veins and nerves with the muscles, so that one may see how the muscles are embraced by these veins and nerves, and take away the sides in order that one may see better how the larger muscle is joined to the shoulder-blade.

Fogli A 14 v.

[*Of the muscles*]

Make a demonstration with muscles lean and thin so that the space that is produced between the one and the other may make a window in order to show that which is found behind them.

As in this representation of a shoulder made here in charcoal.

The muscles are of two shapes with two different names, of which the shorter is called muscle and the longer is called lacert.

NATURE OF MUSCLES

The tendons of the muscles are of greater or less length as a man's fleshy excrescence is greater or less. And in leanness the fleshy excrescence always recedes towards the point at which it starts from the fleshy part. And as it puts on fat it extends towards the beginning of its tendon.

HOW THE MUSCLES ARE ATTACHED TO THE JOINTS OF THE BONES

The end of each muscle becomes transformed into tendon, which binds the joint of the bone, to which this muscle is attached.

OF THE NUMBER OF THE TENDONS AND OF THE MUSCLES

The number of the tendons which successively one above the other cover each other and all together cover and bind the joint of the bones to which they are joined, is as great as the number of the muscles which meet in the same joint.

If the junction of the muscle *b* is made with the bone of the thigh and actually with the muscle *a*, or the muscle *b* and the muscle *a* since they are joined together, they unite and establish themselves upon this bone of the thigh. And this third manner is more useful for the benefit of the movement of this thigh, and more certain, for if the muscle *a* were cut or otherwise injured the muscle *b* would itself move the thigh, which it could not do if it were separated from the bone between *b a*.

Fogli A 15 r.

[*Action of muscles in breathing*]

These muscles have a voluntary and an involuntary movement seeing that they are those which open and shut the lung. When they

open they suspend their function which is to contract, for the ribs which at first were drawn up and compressed by the contracting of these muscles then remain at liberty and resume their natural distance as the breast expands. And since there is no vacuum in nature the lung which touches the ribs from within must necessarily follow their expansion; and the lung therefore opening like a pair of bellows draws in the air in order to fill the space so formed.

Fogli A 15 v.

[*General precepts*]

Begin your anatomy with a man fully grown: then show him elderly and less muscular: then go on to strip him stage by stage right down to the bones.

And you should afterwards make the child so as to show the womb.

[*Relation between size and function of muscles*]

In all the parts where man has to work with greater effort nature has made the muscles and tendons of greater thickness and breadth.

Fogli A 16 r.

[*Function of muscles in breathing*]

TREATS OF MAN ACCORDING TO THE INSTRUMENTAL METHOD AND THE CONTRARY

With the muscles it happens almost universally that they do not move the limb where they are fixed but move that where the tendon that starts from the muscle is joined, except that which raises and moves the side in order to help respiration.

All these muscles serve to raise the ribs and as they raise the ribs they dilate the chest, and as the chest becomes dilated the lung is expanded, and the expansion of the lung is the indrawing of the air which enters by the mouth into this lung as it enlarges.

OF THE DEMONSTRATION OF HOW THE SPINE IS FIXED IN THE NECK

In this demonstration of the neck one will make as many shapes of muscles and tendons as are the uses of the movements of the neck. And the first as is here noted is how the ribs in their strength keep the spine of the neck straight, and by means of the tendons which go up to this spine these tendons serve a double use, that is they support the spine by means of the ribs and support the ribs by means of the spine.

And this duplication of powers situated at the opposite extremities of this tendon works with this tendon in the same manner as the tendon works with the extremities of the arch.

But this convergence of muscles in the spine keeps it upright, just as the ropes of the ship support its mast; and the same ropes bound to the mast also support in part the edges of the ships to which they are joined.

OF THE METHOD OF REPRESENTING THE CAUSES OF THE MOVEMENTS OF ANY LIMB

Make first the motor muscles of the bone called the humerus; then make in the humerus the motor muscles of the arm which cause it to straighten or bend; then show separately the muscles that have their origin in this humerus, which only serve to turn back the arm when it turns the hand upside down; then represent in the arm only the muscles which move the hand up and down and from side to side without moving the fingers in it; then represent the muscles which merely move the fingers, locking them together or extending them or spreading them out or bringing them together; but first represent the whole as is done in the cosmography, and then divide it into the aforesaid parts, and do the same for the thigh, the leg and the feet.

OF THE MUSCLES THAT START IN THE RIBS REPRESENTED ABOVE

I have for a long time and not without reason doubted whether the muscles which start beneath the shoulder-blades above the third, fourth and fifth right rib, and the same also on the left side, are made for the purpose of keeping straight the spinal column of the neck to which they attach themselves with their tendons, or whether in fact these muscles, as they contract, draw themselves together with the ribs towards the nape of the neck, by means of the aforesaid tendons attached to the spinal column; and reason moves me to believe that these muscles are intended to support the spinal column, so that it may not bend in having to support the heavy head of the man, as it bends down or is raised, for the help of which the muscles of the shoulders or of the pit of the throat do not serve, seeing that the man will relax these which start in the shoulders or the pit of the throat when he raises his shoulders towards his ears, and will so take away force from his muscles; and by this loosening and contracting the movement of the neck will not be

impeded, nor will the resistance of the spinal column in supporting this head. And I am further confirmed in this same opinion by the powerful shape of the ribs where these muscles are situated, which is extremely adapted to resist every weight or force which would draw the tendon *a b* in the contrary direction, which drawing it against the rib *b r* fixes it in greater power in the position *r*. And if this tendon had to raise the rib in order to facilitate and increase the breathing, nature would have placed this cord not in the slant *a b*, but in the greater slant *a c*. And read the propositions set forth below and in the margin, which are to the purpose.

Fogli A 16 v.

[*Muscles of hand, leg and foot. Dated note:* 1510]

When you represent the hand represent with it the arm as far as the elbow, and with this arm the sinews and muscles which come to move this arm away from the elbow. And do the same in the demonstration of the foot.

All the muscles that start at the shoulders, the shoulder-blade and the chest, serve for the movement of the arm from the shoulder to the elbow. And all the muscles that start between the shoulder and the elbow, serve for the movement of the arm between the elbow and the hand. And all the muscles that start between the elbow and the hand, serve for the movement of the hand. And all the muscles that start in the neck, serve for the movement of the head and shoulders.

When you represent the muscles of the thigh, represent with these the bone of the leg, so that one may know where these muscles attach themselves to these bones of the legs.

You will then make the leg with its muscles attached to the bones of the leg, and make the bones bare. And you will follow the same plan for all the sinews.

The muscles of the feet serve for the movement of its toes, and in this movement they are aided by the tendons which spring from the muscles of the leg.

Which are the muscles of the leg which serve merely for the simple movement of the foot, and which are those of this leg that serve merely for the simple movement of the toes of this foot? And remember, in clothing the bones of the leg with its muscles to represent first the muscles that move the feet, which you will join to the feet.

Represent here the foot of the bear, the monkey and other animals,

in so far as they differ from the foot of man; and put also the feet of some of the birds.

The muscles of the leg from the knee to the joint of the foot are as many in number as the tendons attaching to the upper part of the toes of the feet; and it is the same below, adding to them those which move the feet upwards and downwards and to and fro, and of these those which raise the toes are five. And there are as many muscles of the feet above and below as the number of the fingers doubled. But as I have not yet finished this discourse I will leave it for the present, and this winter of the year 1510 I look to finish all this anatomy.

The tendons that lower the toes of the feet start from the muscles which have their beginning in the sole of this foot; but the tendons that raise these toes do not have their beginning in the outer part of the thigh as some have written, but they start in the upper part of the foot called the instep. And if you desire to make certain of this, clasp the thigh with your hands a little above the knee and raise the toes of the feet, and you will perceive that the flesh of your thigh will not have any movement in it in its tendons or muscles; so it is quite true.

Fogli A 17 r.

[*Precepts for the study of the foot*]

Use the same rule for the foot that you have used for the hand; that is representing first the bones from six aspects, namely: behind, in front, below and above, on the inside and on the outside.

[*Considerations upon the origin of the muscles of the foot*]

Mondinus says that the muscles which raise the toes of the feet are to be found in the outer part of the thigh; and then adds that the back of the foot has no muscles because nature has wished to make it light so that it should be easy in movement, as if it had a good deal of flesh it would be heavier; and here experience shows that the muscles *a b c d* move the second pieces of the bones of the toes; and that the muscles of the leg *r S t* move the points of the toes. Here then it is necessary to enquire why necessity has not made them all start in the foot or all in the leg; or why those of the leg which move the points of the toes should not start in the foot instead of having to make a long journey in order to reach these points of the toes; and similarly those that move the second joints of the toes should start in the leg.

[*Precepts*]

Set down first the two bones of the leg from the knee to the foot, then show the first muscles that start upon the said bones, and proceeding thus you will make one above the other in as many different demonstrations as are the stages in their positions, one above the other; and you will do it thus as far as the end of one side, and you will do the same for four sides in their entirety with all the foot, because the foot moves by means of tendons which start in these muscles of the leg; but the side where is the sole is moved with muscles that start in this sole; and the membranes of the joints of the bones start from the muscles of the thigh and of the leg.

After you have made the demonstration of the bone, show next how it is clothed by those membranes which are interposed between the tendons and these bones.

Remember, in order to make certain as to the origin of each muscle, to pull out the tendon produced by this muscle in such a way as to see this muscle move and its commencement upon the ligaments of the bones.

Avic[enna]. The muscles that move the toes of the feet are sixty.

[*By way of note*]

You will make nothing but confusion in your demonstration of the muscles and their positions, beginnings and ends, unless first you make a demonstration of the fine muscles by means of threads; and in this way you will be able to represent them one above another as nature has placed them; and so you will be able to name them according to the member that they serve, that is, the mover of the point of the big toe, and of the middle bone, or the first bone, etc.

And after you have given these details you will show at the side the exact shape and size and position of each muscle; but remember to make the threads that denote the muscles in the same positions as the central lines of each muscle, and in this way these threads will show the shape of the leg and their distance in rapid movement and in repose.

[*The extensor and flexor muscles of the foot*]

The muscles which are only used to move the foot as it rises forward are *m n*, which start in the leg from the knee downwards; and those which bend it towards the outside of the ankle are the muscles *f n*; therefore *n* is common to both these movements.

[*Atrophy of the muscles*]

I have stripped of skin one who by an illness had been so much wasted that the muscles were worn away and reduced to a kind of thin pellicle, in such a way that the tendons instead of becoming converted into muscle were transformed into loose skin; and when the bones were clothed with skin their natural size was but slightly increased.

[*Topography of the muscles and motor and sensory nerves of the lower limb*]

You will show first the bones separated and somewhat out of position, so that it may be possible to distinguish better the shape of each piece of bone by itself. Afterwards you join them together in such a way that they do not diverge from the first demonstration, except in the part which is occupied by their contact. Having done this you will make the third demonstration of those muscles that bind the bones together. Afterwards you will make the fourth of the nerves which convey sensation. And then follows the fifth of the nerves that move or give direction to the first joints of the toes. And in the sixth you will make the muscles above the feet where are ranged the sensory nerves. And the seventh will be that of the veins which feed these muscles of the foot. The eighth will be that of the nerves that move the points of the toes. The ninth of the veins and arteries that are interposed between the flesh and the skin. The tenth and last will be the completed foot with all its powers of feeling. You will be able to make the eleventh in the form of a transparent foot, in which one is able to see all the aforesaid things.

[*Precepts for the study of the leg*]

But make first the demonstration of the sensory nerves of the leg, and their ramification, from four aspects, so that one may see exactly from whence these nerves have their origin; and then make a representation of a foot young and soft with few muscles.

All the nerves of the legs in front serve the points of the toes, as is shown with the great toe.

[*By way of note*]

After making your demonstrations of the bones from various aspects then make the membranes which are interposed between the bones and

the muscles; and in addition to this, when you have represented the first muscles, and have described and shown their method of working, make the second demonstration upon these first muscles, and the third demonstration upon the second, and so in succession.

Make here first the simple bones, then clothe them gradually stage by stage in the same way that nature clothes them.

When defining the foot it must necessarily be joined with the leg as far as the knee, because in this leg start the muscles which move the points of the toes, that is the final bones.

In the first demonstration the bones should be somewhat separated one from another, in order that their true shape may be revealed. In the second the bones should be shown sawn through, in order that it may be seen what part is hollow and what part solid. In the third demonstration these bones should be joined together. In the fourth should be the ligaments that connect one of these bones with another. In the fifth the muscles that strengthen these bones. Sixth the muscles should be shown with their tendons. Seventh the muscles of the leg with the tendons that go to the toes. Eighth the nerves of sensation. Ninth the arteries and veins. Tenth the muscular skin. Eleventh the foot in its final beauty.

And each of the four aspects should have these eleven demonstrations.

Fogli A 18 r.

[*Notes*]

Of the nerves which raise the shoulders and which raise the head, and those which lower it and which turn it and which bend it across:

To lower the back. To bend it. To twist it. To raise it.

You will write upon physiognomy.

I find that the veins serve no other function than to heat, as nerves and things that have to give sensation.

Fogli B I r.

[*Vital functions of the body*]

Cause of breathing.

Cause of the movement of the heart.

Cause of vomiting.

Cause of the food descending into the stomach.

Cause of the emptying of the intestines.

Cause of the movement of the superfluous matter through the intestines.

Cause of swallowing.
Cause of coughing.
Cause of yawning.
Cause of sneezing.
Cause of the numbness of various limbs.
Cause of loss of sensation in any limb.
Cause of the tickling sensation.
Cause of sensuality and other necessities of the body.
Cause of urination.
And so of all the natural actions of the body. Fogli B I v.

The sense of touch clothes all the surface skin of man.

HOW THE FIVE SENSES ARE THE MINISTERS OF THE SOUL

The soul apparently resides in the seat of the judgment, and the judgment apparently resides in the place where all the senses meet, which is called the common sense; and it is not all of it in the whole body as many have believed, but it is all in this part; for if it were all in the whole, and all in every part, it would not have been necessary for the instruments of the senses to come together in concourse to one particular spot; rather would it have sufficed for the eye to register its function of perception on its surface, and not to transmit the images of the things seen to the sense by way of the optic nerves; because the soul — for the reason already given — would comprehend them upon the surface of the eye.

Similarly, with the sense of hearing, it would be sufficient merely for the voice to resound in the arched recesses of the rock-like bone which is within the ear, without there being another passage from this bone to the common sense, whereby the said mouth might address itself to the common judgment.

The sense of smell also is seen to be forced of necessity to have recourse to this same judgment.

The touch passes through the perforated tendons and is transmitted to this sense; these tendons proceed to spread out with infinite ramifications into the skin which encloses the body's members and the bowels. The perforating tendons carry impulse and sensation to the subject limbs; these tendons passing between the muscles and the sinews dictate

to these their movement, and these obey, and in the act of obeying they contract, for the reason that the swelling reduces their length and draws with it the nerves, which are interwoven amid the particles of the limbs, and being spread throughout the extremities of the fingers, they transmit to the sense the impression of what they touch.

The nerves with their muscles serve the tendons even as soldiers serve their leaders, and the tendons serve the common sense as the leaders their captain, and this common sense serves the soul as the captain serves his lord.

So therefore the articulation of the bones obeys the nerve, and the nerve the muscle, and the muscle the tendon, and the tendon the common sense, and the common sense is the seat of the soul, and the memory is its monitor, and its faculty of receiving impressions serves as its standard of reference.

How the sense waits on the soul, and not the soul on the sense, and how where the sense that should minister to the soul is lacking, the soul in such a life lacks conception of the function of this sense, as is seen in the case of a mute or one born blind.

Fogli B 2 r.

How the nerves sometimes work of themselves, without the command of other agents or of the soul:

This appears clearly for you will see how paralytics or those who are shivering or benumbed by cold move their trembling limbs such as the head or the hands without permission of the soul; which soul with all its powers cannot prevent these limbs from trembling. The same happens in the case of epilepsy or with severed limbs such as the tails of lizards.

FUNCTION OF LIVER, BILE, AND INTESTINES

The liver is the distributor and dispenser of vital nourishment to man.

The bile is the familiar or servant of the liver which sweeps away and cleans up all the dirt and superfluities left after the food has been distributed to the members by the liver.

The intestines. As to these you will understand their windings well if you inflate them. And remember that after you have made them from four aspects thus arranged you then make them from four other

aspects expanded in such a way that from their spaces and openings you can understand the whole, that is, the variations of their thicknesses.

Fogli B 2 v.

[*Chyle. Mesentery*]

By the ramification of the vein of the chyle in the mesentery nourishment is drawn from the corruption of the food in the intestines, and in the last instance it returns by the final ramifications of the artery to these intestines where this blood being afterwards dead it is corrupted and acquires the same stench as comes from the faeces.

The mesentery is a thick sinewy and greasy membrane in the ramifications of which are twelve chief veins, and it is joined to the lower part of the diaphragm.

See whether the mesentery has arteries or no.

In this mesentery are planted the roots of all the veins, which unite at the gate of the liver and purify the blood in the liver; and it then enters the vein of the chyle, and this vein goes to the heart and makes purer the blood which penetrates in the arteries as spirituous blood.

Fogli B 3 r.

OF THE FORCE OF THE MUSCLES

If any muscle whatsoever be drawn out lengthwise a slight force will break its fleshy tissue; and if the nerves of sensation be drawn out lengthwise slight power tears them from the muscles where their ramification weaves them together and spreads and consumes itself; and one sees the same process enacted with the sinewy covering of the veins and arteries which are mingled with these muscles. What is therefore the cause of so great a force of arms and legs which is seen in the actions of any animal whatsoever? One cannot say other than that it is the skin which clothes them; and that when the nerves of sensation thicken the muscles these muscles contract and draw after them the tendons in which their extremities become converted; and in this process of thickening they fill out the skin and make it drawn and hard; and it cannot be lengthened out unless the muscles become thinner; and not becoming thinner they are a cause of resistance and of making strong the before mentioned skin, in which the swollen muscles perform the function of a wedge.

[*Precepts for demonstrations*] [*With drawing*]

Only represent in this demonstration the first upper rib, for this of itself suffices to show where the neck is divided from the bust.

Represent the proportionate length and thickness that the nerves of the arms and legs have to each other.

[*Of the neck*]

You will use extreme diligence in making this demonstration of the neck inside, outside and in profile, and the proportions of the tendons and of the nerves between them, and with the positions where they begin and end; for if you were to do otherwise you would neither be able to treat of nor demonstrate the office or use for which nature or necessity has intended them. And in addition to this you should describe the distances interposed between the nerves themselves both as regards their depth and breadth, and the differences in the heights and depths of their origins; and you will do the like with the muscles veins and arteries; and this will be extremely useful to those who have to dress wounds.

Fogli B 3 v.

[*Umbilical vein*]

Note if the umbilical veins are four both in males and females.

By *x v* umbilical vein is composed the life and the body of every animal of four feet, except those that start from the egg, such as frogs, tortoises, green lizards, chameleons and the like.

I believe that these four nerves are those of the reins or arteries.

I have found that they are of the greater veins of the reins.

The navel is the gate from which our body is formed by means of the umbilical vein.

Fogli B 4 r.

This demonstration is as necessary for good draughtsmen as the derivation from Latin words is to good grammarians; for anyone must needs make the muscles of figures badly in their movements and actions unless he knows which are the muscles that are the cause of their movements.

Fogli B 4 v.

[*Reason for position of veins in knee*]

Nature has placed the principal veins of the leg in the middle of the thickness of the knee joint, because in the process of bending this joint the veins are less compressed than if they were situated in front of or behind the knee.

[*Relation of nerves with muscles*]

There are as many ramifications of the nerves as there are muscles, and there cannot be either more or less, because these muscles can only be contracted or distended by reason of these nerves from which the muscles receive their sensation. And there are as many tendons that move the limbs as there are muscles.

Fogli B 5 r.

[*Nerves*]

The nerves in some parts of a man are round, in others flat.

The nerves start lower than the veins of the kidneys.

There are as many nerves as there are muscles in the thigh.

Fogli B 6 r.

The vertebrae of the back behind the kidneys number five.

[*List of anatomical demonstrations*]

Three men complete.

Three with bones and veins.

Three with bones and nerves.

Three with simple bones.

These are twelve demonstrations of whole figures.

Fogli B 6 v.

The vein *saphena* with its other collaterals and adherents which serve to supply the nourishment of the thigh ought to be inclosed by the lines that form the boundaries of the whole leg.

Fogli B 8 r.

At about the centre of the height, breadth and bulk of the man there is more intricacy of structure than in any other part of him; and it is even greater in the woman who in the same part has bladder, womb, ovaries, rectum, hæmorrhoidal veins, nerves, muscles, cartilages and like things.

Fogli B 8 v.

Draw the arm of Francesco the miniaturist which shows many veins.

[*Precepts for anatomical drawings and demonstrations*]

In demonstrations of this kind you should show the exact contours of the limbs by a single line; and in the centre place their bones with the true distances from their skin, that is the skin of the arm; and then you will make the veins which may be whole upon a clear ground; and

thus there will be given a clear conception as to the position of the bone, vein and nerves.

[*Changes of the arteries in age*]

In proportion as the veins become old they lose their straightness of direction in their ramifications, and become so much the more flexible or winding and of thicker covering as old age becomes more full with years.

You will find almost universally that the passage of the veins and the passage of the nerves are on the same path, and direct themselves to the same muscles and ramify in the same manner in each of these muscles, and that each vein and nerve pass with the artery between one muscle and the other, and ramify in these with equal ramification.

[*Expansibility of the vessels*]

The veins are extensible and expansible; and of this there is testimony afforded in the fact that I have seen one who has chanced to wound the common vein and has immediately bound it up again with a tight bandage and in the space of a few days there has grown a blood-coloured tumour as large as a goose's egg, full of blood, and it has remained so for several years; and I have also found in the case of a decrepit man that the mesaraic veins have contracted the passage of the blood and doubled in length.

Fogli B 10 r.

[*Changes of the arteries, hepatic veins, and abdominal organs in the old*]

The artery and the vein which in the old extend between the spleen and the liver, acquire so great a thickness of skin that it contracts the passage of the blood that comes from the mesaraic veins, through which this blood passes over to the liver and the heart and the two greater veins, and as a consequence through the whole body; and apart from the thickening of the skin these veins grow in length and twist themselves after the manner of a snake, and the liver loses the humour of the blood which was carried there by this vein; and consequently this liver becomes dried up and grows like frozen bran both in colour and substance, so that when it is subjected even to the slightest friction this substance falls away in tiny flakes like sawdust and leaves the veins and arteries.

And the veins of the gall and of the navel which entered into this liver by the gate of the liver all remain deprived of the substance of this liver, after

the manner of maize or Indian millet when their grains have been separated.

The colon and the other intestines in the old become much constricted, and I have found there stones in the veins which pass beneath the fork of the breast, which were as large as chestnuts, of the colour and shape of truffles or of dross or clinkers of iron, which stones were extremely hard, as are these clinkers, and had formed bags which were hanging to the said veins after the manner of goitres.

And this old man, a few hours before his death, told me that he had lived a hundred years, and that he did not feel any bodily ailment other than weakness, and thus while sitting upon a bed in the hospital of Santa Maria Nuova at Florence, without any movement or sign of anything amiss, he passed away from this life.

And I made an autopsy in order to ascertain the cause of so peaceful a death, and found that it proceeded from weakness through failure of blood and of the artery that feeds the heart and the other lower members, which I found to be very parched and shrunk and withered; and the result of this autopsy I wrote down very carefully and with great ease, for the body was devoid of either fat or moisture, and these form the chief hindrance to the knowledge of its parts.

The other autopsy was on a child of two years, and here I found everything the contrary to what it was in the case of the old man.

The old who enjoy good health die through lack of sustenance. And this is brought about by the passage to the mesaraic veins becoming continually restricted by the thickening of the skin of these veins; and the process continues until it affects the capillary veins, which are the first to close up altogether; and from this it comes to pass that the old dread the cold more than the young, and that those who are very old have their skin the colour of wood or of dried chestnut, because this skin is almost completely deprived of sustenance.

And this network of veins acts in man as in oranges, in which the peel becomes thicker and the pulp diminishes the more they become old. And if you say that as the blood becomes thicker it ceases to flow through the veins, this is not true, for the blood in the veins does not thicken because it continually dies and is renewed.

Fogli B 10 v.

[*Principal vessels of the thorax*]

You will make the veins which are in the heart and also the arteries which give it life and nourishment.

[*Heart and vessels*]

The heart is the nut which produces the tree of the veins; which veins have their roots in the dung, that is the mesaraic veins which proceed to deposit the blood they have acquired in the liver from which afterwards the upper veins of the liver are nourished.

[*Precepts for anatomical drawings*]

Make first the ramification of the veins by themselves, then the bones by themselves, and then join the bones and veins together.

[*Heart and vessels proceeding from the heart, and comparison with the roots and ramifications of plants*]

The plant never springs from the ramification for at first the plant exists before this ramification, and the heart exists before the veins.

All the veins and arteries proceed from the heart; and the reason is that the maximum thickness that is found in these veins and arteries is at the junction that they make with the heart; and the farther away they are from the heart the thinner they become and they are divided into more minute ramifications. And if you should say that the veins start in the protuberance of the liver because they have their ramifications in this protuberance, just as the roots of plants have in the earth, the reply to this comparison is that plants do not have their origin in their roots, but that the roots and the other ramifications have their origin in the lower part of these plants, which is between the air and the earth; and all the parts of the plant above and below are always less than this part which borders upon the earth; therefore it is evident that the whole plant has its origin from this thickness, and, in consequence, the veins have their origin in the heart where is their greatest thickness; never can any plant be found which has its origin in the points of its roots or other ramifications; and the example of this is seen in the growing of the peach which proceeds from its nut as is shown above.

Fogli B 11 r.

[*Precepts for the measurements of the fingers*]

Give the measurements for the fingers of man, anatomized from every limb and its positions.

[*Alterations in the inner coating of the blood vessels in the old*]

One asks why the veins in the old acquire great length, and those

which used to be straight become bent, and the skin thickens so much as to close up and stop the movement of the blood, and from this arises the death of the old without any disease.

I consider that a thing which is nearer to that which feeds it increases more; and for this reason these veins being a sheath of the blood that nourishes the body it nourishes the veins so much the more as they are nearer to the blood.

[*Arteries of the abdomen. Causes of death in the old*]

The veins *a b* become so much constricted in the old that the blood loses its power of movement through them, and so usually becomes foul, and can no longer penetrate the new blood which sweeps it away as it used to do as it comes from the gate of the stomach, whence this good blood grows corrupt away from the bowels, and so the old fail without fever when they are of great age.

And why the bowels in the old are much constricted.

[*Impossibility of the removal of the spleen in the living*]

It is shown here that it is impossible to remove the spleen from men as is believed by those who are ignorant of its constituent substance, because as is here shown it cannot be extracted from bodies without causing death; and this happens because of the veins with which it nourishes the stomach.

[*Vessels which provide for the nutrition of the abdominal organs*]

The vein which extends between the gate of the liver and the gate of the spleen has its roots with five ramifications that ramify in the five coverings of the liver, and at the middle of its trunk there starts a branch which spreads out in nourishment from the base of the peritoneum and extends in all its parts. And a little farther away a branch raises itself up and joins itself to the left part below the stomach, and then ends somewhat farther on in two branches at the junction with the spleen, and goes ramifying through all its substance.

[*Cause of death in the old*]

Veins which by the thickening of their tunicles in the old restrict the passage of the blood, and by this lack of nourishment destroy their life without any fever, the old coming to fail little by little in slow death.

And this happens through lack of exercise since the blood is not warmed.

Fogli B 11 v.

OF THE REASON OF THE HEAT OF THE BLOOD

The heat is produced by the movement of the heart, and this manifests itself because in proportion as the heart moves more swiftly the heat increases more, as is shown by the pulse of those suffering from fever which is moved by the beating of the heart.

[*Drawing of heart — below:—*]

Marvellous instrument, invented by the supreme Master.

[*Mechanism of action of the heart*]

Heart open in the receptacle of the spirits, that is in the artery; and in M it takes or rather gives the blood to the artery, and by the mouth, B, it refreshes itself with air from the lung, and by C it fills the auricles of the heart S.

N Firm muscle is drawn back, and it is the first cause of the movement of the heart, and as it draws back it thickens, and as it thickens it becomes shortened and draws back with it all the lower and upper muscles, and closes the door M, and shortens the space that intervenes between the base and the apex of the heart, and consequently comes to empty it and to draw to itself the fresh air.

Fogli B 12 r.

Of the heart. This moves of itself and does not stop unless for ever.

[*Function of the lung in relation to the circulation*]

Of the lung. This is moved by others, that is, by the first mover which is the heart which as it becomes constricted draws the veins after it, with which it restores the heated air to the lung, and opens it, and this lung can close either voluntarily or through oblivion, that is, forgetfulness through excess of thought; and by this means the heart draws back from it the heated air which it has given it; but this act cannot be repeated many times for if it were not for its refreshing itself with new air it would come to suffocate.

Testicles, witnesses of coition. These contain in themselves ardour that is they are augmenters of the animosity and ferocity of the animals; and experience shows us this clearly in the castrated animals, of which

one sees the bull, the boar, the ram and the cock, very fierce animals, which after having been deprived of these testicles remain very cowardly; so one sees a ram drive before it a herd of wethers, and a cock put to flight a number of capons; and I have seen the same thing happen with a hen, and also with oxen.

Della verga. This confers with the human intelligence and sometimes has intelligence of itself, and although the will of the man desires to stimulate it it remains obstinate and takes its own course, and moving sometimes of itself without licence or thought by the man, whether he be sleeping or waking, it does what it desires; and often the man is asleep and it is awake, and many times the man is awake and it is asleep; many times the man wishes it to practise and it does not wish it; many times it wishes it and the man forbids it. It seems therefore that this creature has often a life and intelligence separate from the man, and it would appear that the man is in the wrong in being ashamed to give it a name or to exhibit it, seeking the rather constantly to cover and conceal what he ought to adorn and display with ceremony as a ministrant.

[*Organs which function independently of the will*]

No inferior instrument in the human body is able to suspend its action voluntarily except the lung. You see the heart which carries on its function of itself, and the stomach also and the other intestines which are joined to it, and similarly the liver the gall the spleen the testicles the kidneys and the bladder.

Fogli B 13 r.

In fact man does not vary from the animals except in what is accidental, and it is in this that he shows himself to be a divine thing; for where nature finishes producing its species there man begins with natural things to make with the aid of this nature an infinite number of species; and as these are not necessary to those who govern themselves rightly as do the animals it is not in their disposition to seek after them.

[*Drawing of right kidney*]

Cut it through the centre and represent how the channels of the urine are constricted and how they fall drop by drop.

Describe the distance of these kidneys from the flanks and the false ribs.

Fogli B 13 v.

[Passage of the urine from the kidneys into the bladder by means of the ureters]

The authorities say that the uretary ducts do not enter directly to carry the urine to the bladder; but that they enter between skin and skin by ways that do not meet each other; and that the more the bladder becomes filled the more they become contracted; and this they say nature has done merely in order that when the bladder is filled it should turn the urine backwards whence it came; in such a way that in finding the ways between membrane and membrane to penetrate into the interior by narrow ways and not opposite to that of the first membrane, the more the bladder is filled, the more it presses one membrane against the other, and consequently it has no cause to spread itself out and turn back. This proof however does not hold, seeing that if the urine were to rise higher in the bladder than its entrance which is near the middle of its height it would follow that this entrance would suddenly close and no more urine would be able to pass into the bladder and the quantity would never exceed the half of the capacity of this bladder; the remainder of the bladder therefore would be superfluous, and nature does not create anything superfluous. We may say therefore, by the fifth [section] of the sixth [book] concerning waters, that the urine enters the bladder by a long and winding way, and when the bladder is full the uretary ducts remain full of urine, and the urine that is in the bladder cannot rise higher than their surface when the man is upright; but if he remains lying down it can turn back through these ducts, and even more can it do this if he should put himself upside down which is not often done; but the recumbent position is very usual, in which if a man lies on his side one of the uretary ducts remains above the other below; and that above opens its entrance and discharges the urine into the bladder, and the other duct below closes because of the weight of the urine; consequently a single duct transmits the urine to the bladder, and it is sufficient moreover that one of the emulgent veins purify the blood of the chyle of the urine which is mixed with it because these emulgent veins are opposite to one another and do not all proceed from the vein of the chyle. And if the man sets himself with his back to the sky both the two uretary ducts pour urine into the bladder, and enter through the upper part of the bladder, because these ducts are joined in the back part of the bladder, and this part remains above when the body is facing downwards, and consequently the entrances of the urine are able to

stand open, and to supply so much urine to the bladder that it fills it.

When the man is upside down the entrance of the urine is closed.

Fogli B 14 r.

[*Reason of the arrangement of the human intestine in relation to nutrition*]

Animals without legs have a straight bowel, and this is why it always remains lying down, for the animal not having feet cannot raise itself on them, and if it should raise itself it returns immediately to a level position; but in the case of the man this would not take place by reason of his holding himself quite straight, because the stomach would suddenly empty itself if the twisted nature of the intestines did not check the descent of the food; and if the bowel were straight each part of the food would not come in contact with the bowels as it does in the twisted bowels.

And consequently there would remain much nutritive substance in the superfluous parts of this food which would not be able to be sucked by the substance of these bowels and transported in the mesaraic veins.

[*Defecation. Intestinal movements in relation to the diaphragm*]

When with the transversal muscles of the body one presses out the superfluous parts from the intestines, these muscles would not perform their function well or powerfully unless the lung were filled with air; seeing that if this lung were not full of air it would not fill with itself all the diaphragm; consequently this diaphragm remains loose, and the intestines pressed by the said transversal muscles bend towards the side that gives way to them, which would be the diaphragm. But if this lung should stay full of air and you do not afford it outlet above, then the diaphragm is taut and firm and offers resistance to the rising up of the intestines when pressed by the transversal muscles; consequently of necessity the intestines rid themselves through the straight intestine of a great part of the superfluity which is enclosed within them.

[*Precepts for the study of the liver*]

I wish to cut the liver which covers the stomach in that part which covers the stomach as far as the vein which enters and afterwards emerges from this liver, and to see how this vein ramifies through this liver. But first I will have represented how all this liver stands and how it clothes the stomach.

Fogli B 14 v.

All the muscles of the body are enveloped in extremely thin cartilage, and then they become changed to thicker cartilage and in that their substance ends.

[*Action of the transversal muscles of the abdomen upon defecation*]

The transversal muscles squeeze the intestines but not the longitudinal ones, because if it were so when the man holds himself bent and relaxes these muscles he would not have force to perform the office of squeezing them; but the transversal muscles never relax as the man bends but rather become stretched.

[*Muscles of the anterior wall of the abdomen and their function*]
[*Drawing n r b a s h m*]

a b are final longitudinal muscles; the membranes in which they become transformed pass at a right angle below the longitudinal *a m*.

The muscles *n r s h* are four and have five tendons and were not made of a single piece as the others, so that each was shorter; although where there is life with thickness there is strength, and where there is such great length of movement there it is necessary to divide the mover into several parts, and its greater extension exceeds its lesser extension by the third part of one of its arms, and by so much more as it makes greater concavity of arch in its back, as one sees done by those contortionists who bend themselves so far backwards that they cause their hands to touch their feet, and this excess of capacity is produced by the contraction of their feet with their hands, and these muscles are made in two rows, that is right and left, from the necessity of bending to right and left.

The transversal muscles *c d* are those which, as they are drawn, constrict and raise the intestines and push up the diaphragm and drive out the air from the lung; afterwards as these muscles become relaxed the bowels drop and draw back the diaphragm and the lung opens.

a b is all made up of cartilage which borders on the sifac and starts from the fleshy muscles *c d*, which muscles enter under the ribs and are latitudinal muscles starting in the bone of the spine, and it is these alone which squeeze out the superfluities from the body.

Above the membrane *a b* descend the longitudinal muscles *n m*, mentioned above, which start in the last ribs, [run up] to the side of the Adam's apple and end below in the pubis. Fogli B 15 r.

[*Muscles of the trunk*]

Note how the flesh increases above the bone as one grows fat, and how it decreases as one grows thin, and what shape it assumes and . . .

The muscle *a b* becomes fleshy at its end beneath the arm and in the upper part and in the lateral, or lower in the flank, and behind in the bone of the back, and in front in the middle longitudinal section of the body, and behind it ends in the vertebrae of the spine.

The muscles *n m o p q* are situated above the ribs, and with their angles they are converted into short thick cartilage, and they unite with the ribs where they rest, and immediately there start other muscles namely *a m n*, and that which is shown appears after the skin has been removed.

a b c is covered by the muscle *a* above, in the second demonstration.

All the muscles which start in the body are converted into membranes, which membranes continue with the opposite muscle, passing above the lower part of the belly, as are the transversal and the slanting muscles; but the longitudinal or straight muscles go fleshy from the height of the Adam's apple to the pubis; and the muscle of the breasts which starts from all the middle of the thorax and ends in the bone of the shoulder, when it has passed a short distance below the breasts is converted into membrane and clothes the whole body.

Fogli B 15 v.

The first muscle of the lower part of the belly starts in its upper part in the sixth rib of the breast and ends towards the arms after the manner of a saw in the muscles which start over the ribs, and below being changed into cartilage it ends in the bone of the hip as far as the pubis.

The muscle *n m* is the lower transversal, which starts in the vertebrae behind the navel, passes through the soft parts of the flank, and ends in the penultimate false rib, and becomes changed into cartilage above the longitudinal muscles; it becomes fleshy and continues as far as the pubic region.

Fogli B 16 r.

[*Precepts for the demonstration of the muscles of the thorax*]

The demonstration of the region of the ribs requires first the plain sides bare with open spaces; afterwards the muscles which are joined to their sides with which they are chained together; then the muscles that interlace above them which serve for the movements of expansion and

contraction of these sides; in addition to this the other muscles crossed above the aforesaid muscles, at different angles, serving for various movements.

[*Reason of the movement of the ribs*]

Of the maximum raising and lowering of the shoulders which checks the movement of the sides. Because the maximum raising and lowering of the shoulders by means of the muscles of the neck which have their base in the vertebrae of the spine, impedes when these shoulders are raised, the movement of the ribs in their descent; and as these shoulders are lowered the movement of raising these sides is impeded.

For which fact nature has made provision by means of the muscles of the diaphragm which lower this diaphragm in its concave centre; and when it is raised again this proceeds from the compressed wind enclosed in the intestines, which wind is caused by the fact that the excrements as they dry give off gases; and if the raised shoulders keep the ribs high by means of the muscle *b* then the diaphragm by merely moving itself by means of its muscles performs the function of opening *and closing* the lung; and the compressed intestines together with the condensed wind which is generated in them push back the diaphragm upwards; which diaphragm presses the lung and expels the air.

[*Muscles of the anterior wall of the thorax and of the abdomen*]

The muscle *a* contains in itself the breast, and descends fleshy as far as the seventh rib by the side of the Adam's apple; then having been converted into membrane it proceeds to form a covering over all the lower part of the belly and ends by joining itself to the bone of the pubis; and this muscle of the breast is composed of several muscles which all start in the thorax, and converge and end in the part of the muscles of the humerus.

a d c ends in the bone of the shoulder, and starts in the middle of the thorax, and below it does not go so far as to cover *b*, shown above, except by its cartilage, with which it covers all the lower part of the belly, and it ends in the flank and in the bone of the pubis.

Fogli B 16 v.

[*Lung*]

When the lung has sent out the wind and so is diminished in quantity by an amount corresponding to the amount of the wind which

emerged from it, one ought then to consider from where the space of the cavity of the lessened lung attracts to itself the air which fills up its increase, because in nature there is no vacuum.

And one asks also, since after the lung has been expanded it drives out the air from its receptacle, by what way this air escapes and where it is received after it has escaped.

[*Mechanism of respiration. Action of intercostal muscles*]

The lung is always full of a quantity of air, even when it has driven out that air which is necessary for its exhalation; and when it is refreshed by new air it presses on the sides of the chest, dilates them a little and pushes them outwards, for as may be seen and felt by placing the hand upon the chest during its breathing, the chest expands and contracts, and even more so when one heaves a big sigh. For nature has so willed that this force should be created in the ribs of the chest and not in the membrane that ends the substance of the lung, lest by an excessive ingathering of air in order to form some unusually deep sigh this membrane may come to break and burst itself.

[*Function of the diaphragm*]

The diaphragm, that is the large membrane which is below the points of the lung, is not altered nor pushed in any part by the increase of the lung, for this lung increases in width and not in length, unless this diaphragm has been driven by the wind or air which gives place to the increase of the lung, for it would then be possible for the diaphragm driven by the air to give place to its increase, and for the air to push the liver and the liver the stomach to which it serves as cover, and thus would follow the pushing of all the intestines, and this continual movement would bring about the evacuation of the intestines with so much greater speed as the exercise of the man was performed with greater vigour.

[*Cause of the formation of gas in the intestines*]

Of the wind that is produced in the intestines we may say that it is caused by the superfluous quantity which collects in the rectum, which becomes drier as the moisture in it evaporates more; and this vapour in the form of air distends the bowels and produces pains on finding itself confined within the colon.

[*Latitudinal increase of the lung in breathing. How its expansion acts upon the functions of the stomach*]

The increase of the lung when it is filled with air is latitudinal and not in its length, as may be seen by inflating the lung of a pig; and the air which is interposed between the lung when not inflated and the ribs which surround it, as the lung becomes extended escapes in the part below between the lung and the diaphragm, and causes this diaphragm to swell downwards, against the stomach, whereat this stomach being pressed transmits the things contained within it to the intestines.

[*Action of the expansion of the lungs upon the pericardium and function of the pericardial fluid*]

Moreover this air pressed between the lung and the diaphragm rests in the case which encloses the heart, and that small quantity of fluid which is at the bottom of this case raises itself and bathes the whole heart, and so continually by thus bathing it it moistens the heated heart and prevents it from becoming parched through the extent of its movement.

Fogli B 17 r.

[*Origin of the whole body from the heart*]

The whole body has origin from the heart as regards its first creation; and the blood therefore and the veins and nerves do the like, although these nerves seem manifestly all to start from the spinal marrow, and to be remote from the heart, and the spinal marrow to be of the same substance as the brain from whence it is derived.

[*Origin of the spinal nerves*]

Tree of all the nerves, and it is shown how these all have origin from the spinal marrow and the spinal marrow from the brain.

[*Precepts for the demonstration of the nerves*]

Make in every demonstration of the whole quantity of the nerves the external lineaments which denote the shape of the body.

Fogli B 17 v.

[*Precepts for anatomical demonstrations*]

Remember never to change the contour lines of any limb by any muscle that you remove in order to uncover another; and if you only remove muscles of which one of its contour lines is contour line of a

part of the limb from which you detach it, you ought then to indicate with frequent dots the contour line of that limb which was removed by the separation of any muscle; and this you will do so that the shape of that limb which you describe may not remain an unnatural thing through having its parts taken away. And in addition to this there ensues a greater knowledge of the whole, for when the part has been taken away you see in the whole the true shape of the part whence it was taken.

Fogli B 18 r.

[*Of the muscles*]

The long muscle *a b* and the long muscle *a c* serve to raise the thigh forward.

And they also give this thigh lateral movements, namely in spreading out and contracting these thighs; and the process of the thickening and contraction of the muscle *a c* comes into play in the spreading out of this thigh, and of the long muscle *a b* in its contraction.

[*Of the rotatory movement of the thigh*]

The part of the rotatory movement of the thigh to right and left is caused by the aforesaid muscles; that is the muscle *a c* turns the thigh inward, and the long muscle *a b* turns it back outward, and the two together raise the thigh.

[*Reason of the insertions of the muscles*]

The muscles always begin and end in the bones that touch one another, and they never begin and end in the same bone, for it would not be able to move anything unless this was itself in a state of rarity or density.

Which are the muscles which begin and finish on one side upon one bone and on the other upon another muscle?

[*Topography of muscles of front region of thigh*]

I wish to separate the muscle or tendon *a b* and show that which follows below it.

[*Insertion of the muscles of the thigh at the knee*]

On to the knee arrive all the muscles of the thigh which are changed first into nerve, and then, below the nerve, each is transformed into a

thin cartilage with which is bound the joint of the knee with as many peels or membranous jackets as are the muscles which descend from this thigh to the knee; and these ligaments extend four fingers' space above the joint of the knee and four below.

Fogli B 18 v.

[*Muscles of the thigh in relation to nutrition*]

Which muscles are those which as they become lean divide themselves into several muscles, and form one out of many as they become fleshy?

Fogli B 19 v.

[*Various anatomical themes*]

Ramification of the veins from the shoulders upward, and from the spleen to the lung.

Ramification of the nerves and of the reversive nerves to the heart.

Of the shape and position of the intestines.

Where the umbilical cord is fastened.

Of the muscles of the body and of the kidneys.

[*Origin and insertion of the muscles of the foot*]

The muscles which raise and lower the foot start in the leg; that is those which raise the front part start in the outside part of the leg and stop at the beginning of the big toe.

[*Precepts for the study of tendons*]

Note which are the principal cords and those which inflict greater injury to the animal if they were cut, and which are of less importance; and you will do this for each limb.

[*Precepts for the demonstration of the bones and muscles of the leg*]

Observe the proportion of the bones one with another.

And for what purpose each serves.

In this demonstration made from different aspects you take count of all the muscles which move the leg, which muscles are attached to the edges of the pelvis, in which also start the muscles that move the thigh from the knee upwards.

And also of those which bend the leg when one kneels.

[*Notes concerning the muscles which become uncovered and hide themselves in their movement*]

Different muscles become uncovered in the different movements of the animals, and different muscles are those which hide themselves in such diversity of movement; and concerning this it is necessary to make a long treatise for the purpose of recognising the places that have been injured by wounds, and also for the convenience of sculptors and painters.

[*Origin of the movements of the legs and feet*]

All the movements of the leg start from the muscles of the thigh, which movements are the cause of the bending of the leg, of the straightening of it when bent and of its turning to right or left.

But the movements of the feet are caused by the muscles which start in the leg; of the movements of the toes some start in the leg and some in the foot.

[*Insertion of the motive muscles of the leg*]

And of the motive muscles of the leg part start in the hip and part in the thigh; and of all you will give the true position.

Fogli B 20 r.

OF THE ORDER OF THE BOOK

This work should commence with the conception of man, and should describe the nature of the womb, and how the child inhabits it, and in what stage it dwells there, and the manner of its quickening and feeding, and its growth, and what interval there is between one stage of growth and another, and what thing drives it forth from the body of the mother, and for what reason it sometimes emerges from the belly of its mother before the due time.

Then you should describe which are the limbs that grow more than the others after the child is born; and give the measurements of a child of one year.

Then describe the man fully grown, and the woman, and their measurements, and the nature of their complexions colour and physiognomy.

Afterwards describe how he is composed of veins, nerves, muscles and bones. This you should do at the end of the book.

Then represent in four histories four universal conditions of mankind

namely, joy, with various modes of laughing, and represent the cause of the laughter; weeping, the various ways with their cause; strife with various movements expressive of slaughterings, flights, fear, acts of ferocity, daring, homicide and all the things which connect with cases such as these.

Then make a figure to represent labour, in the act of dragging, pushing, carrying, restraining, supporting and conditions such as these.

Then describe the attitude and movement.

Then perspective through the office of the sight or the hearing. You should make mention of music and describe the other senses.

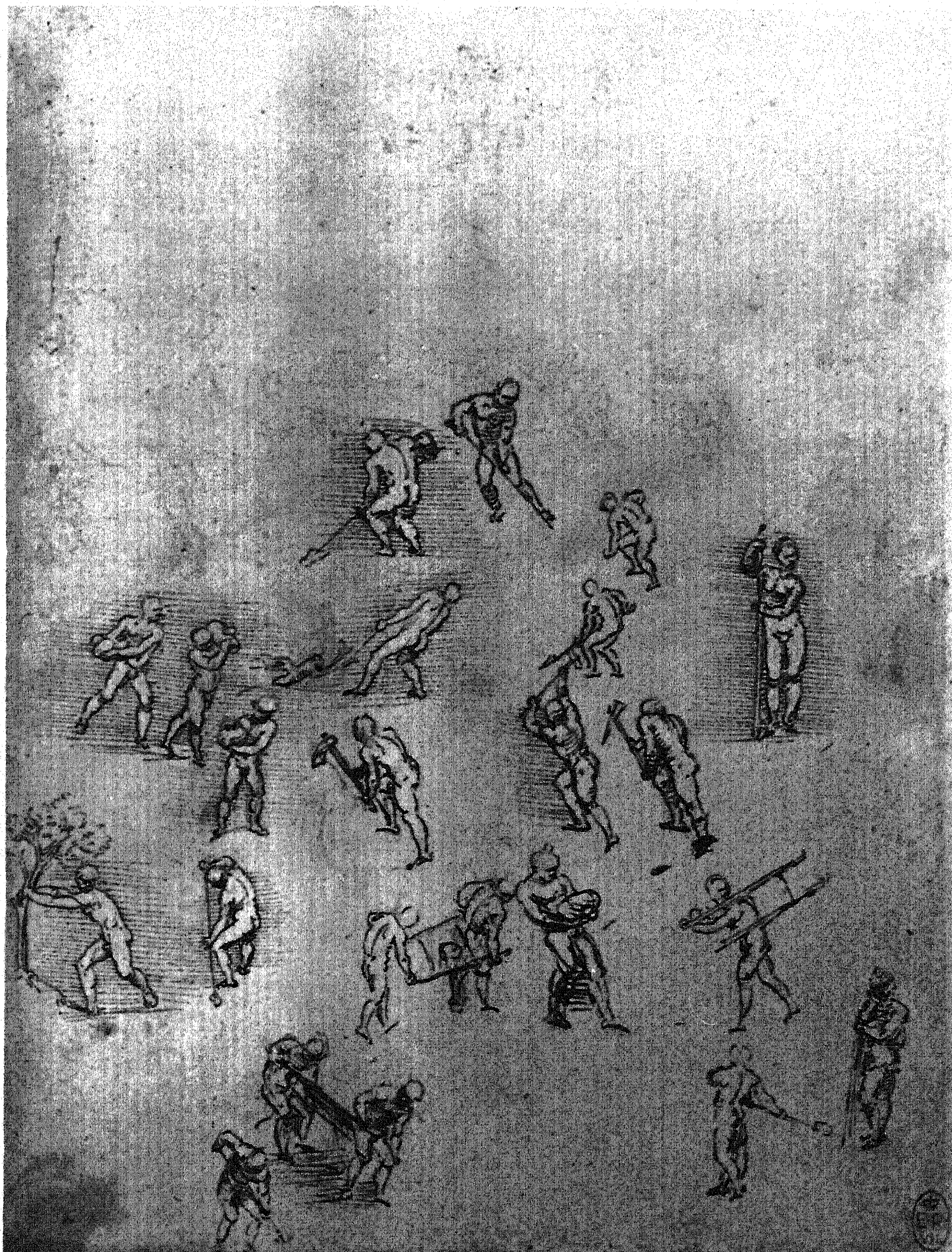
Afterwards describe the nature of the five senses.

We shall describe this mechanical structure of man by means of diagrams of which the three first will treat of the ramification of the bones; that is one from the front which shows the positions and shapes of the bones latitudinally; the second as seen in profile and shows the depth of the whole and of the parts and their position; the third diagram will show the bones from behind. Then we shall make three other diagrams from the same points of view with the bones sawn asunder so as to show their thickness and hollowness; three other diagrams we shall make for the bones entire, and for the nerves which spring from the nape of the neck and showing into what limbs they ramify; and three others for the bones and veins and where they ramify; then three for muscles and three for the skin and the measurements, and three for the woman to show the womb and the menstrual veins which go to the breasts.

Fogli B 20 v.

THEMES PHYSIOLOGICAL AND ANATOMICAL

Figure to show how catarrh is caused.
Tears.
Sneezing.
Yawning.
Trembling.
Epilepsy.
Madness.
Sleep.
Hunger.
Sensuality.



FIGURES TO REPRESENT LABOUR

Royal Library, Windsor

[Text : I. 140]

Anger when it works in the body.

Fear likewise.

Fever.

Disease.

Where poison injures.

Describe the nature of all the limbs.

Why the thunderbolt kills a man and does not wound him, and if the man blew his nose he would not die. Because it hurts the lungs.

Write what the soul is.

Of nature which of necessity makes the vital and actual instruments of suitable and necessary shapes and positions.

How necessity is the companion of nature.

Figure to show from whence comes the semen.

Whence the urine.

Whence the milk.

How nourishment proceeds to distribute itself through the veins.

Whence comes intoxication.

Whence vomiting.

Whence gravel and stone.

Whence colic.

Whence dreaming.

Whence frenzy by reason of sickness.

Why it is that by compressing the arteries a man falls asleep.

Why it is that a prick on the neck may cause a man to drop dead.

Whence come tears.

Whence the turning of the eyes when one draws the other after it.

Of sobbing.

[*Relation of breasts and shoulder-blades in different positions of trunk*]

OF THE REINS WHEN ARCHED

When the reins or the back is arched the breasts are always lower than the shoulder-blades of this back.

And when the chest is arched the breasts are always higher than the shoulder-blades of the back.

When the reins are straight the breasts will always be found of the height of these shoulder-blades.

Fogli B 21 r.

[*Connection between object and sense*]

The object moves the sense.

[*Contrast between the perfection of the body and the coarseness of the mind in certain men*]

Methinks that coarse men of bad habits and little power of reason do not deserve so fine an instrument or so great a variety of mechanism as those endowed with ideas and with great reasoning power, but merely a sack wherein their food is received, and from whence it passes away.

For in truth one can only reckon them as a passage for food; since it does not seem to me that they have anything in common with the human race except speech and shape, and in all else they are far below the level of the beasts.

[*Attitude in ascending*]

In proportion as the step by which a man rises is of greater height his head will be so much the more in front of the foot which is uppermost.

[*Attitude in stopping a course*]

When the man wishes to arrest his course and to consume his impetus, necessity causes him to lean back and to make short quick steps.

[*Mechanism of certain movements of the human body and foundation of human statics*]

The centre of the weight of the man who raises one of his feet from the ground rests above the centre of the sole of the foot.

[*Mechanism of the ascent*]

The man who goes up stairs puts as much of his weight in front and at the side of the upper foot as he puts as counterpoise to the lower leg, and in consequence the work of the lower leg only extends to moving itself.

The first thing that the man does when he ascends by steps is to free the leg which he wishes to raise from the heaviness of the bust which is resting upon this leg, and in addition to this he loads the opposite leg with all the rest of the bulk of the man together with the other leg; then he raises the leg and places the foot upon the step where he wishes to

raise it; having done this he gives back to the higher foot all the rest of the weight of the bust and of the leg, leans his hand upon his thigh, thrusts the head forward and makes a movement towards the point of the higher foot, raising swiftly the heel of the lower foot, and with the impetus thus acquired raises himself up, and at the same time extends the arm which he was resting upon the knee, and this extension of the arm pushes the bust and head upwards and thus straightens the curve of the back.

Fogli B 21 v.

[*Veins*]

OF THE OLD MAN

Veins which mark with their main lines here and there the base of the stomach and proceed to ramify through the network that covers the intestines.

b a c is the vein which extends from the spleen to the gate of the liver and passes behind the stomach, and from *a* divide the vein and the artery which ramify in the net that covers the intestines; that is from *a* there proceed two veins which pass under the bottom of the stomach, the one behind between the ribs and the stomach, and the other in front, and proceed as has been said to ramify through the peritoneum behind and through the peritoneum in front, which is double as the figure shows; and that which the veins do is found to be done by the artery.

[*Change of the vessels in the old*]

I have found in the decrepit how the vein which proceeds from the door of the liver crosses behind the stomach and ramifies in the spleen, as this ramification, the veins in the young being straight and full of blood, and in the old they are twisted, flattened, wrinkled and emptied of blood.

[*Changes in the liver in age*]

And thus the liver which in youth is usually of a deep colour and of uniform consistency, in the old is pale, without any redness of blood, and the veins stay empty amidst the substance of this liver, which substance may be likened for its thin texture to bran steeped in a small quantity of water, and so readily disintegrating on being washed, leaving the veins that ramify within it freed from all the substance of the liver.

Fogli B 22 r.

[*Precepts upon the topography of the intestines*]

Remember to mark the height of the stomach above the navel and with the Adam's apple, and how the spleen and the heart stand with the left breast, and how stand the kidneys or reins with the hips, and the colon and bladder and other intestines, and how much more or less remote they are from the spine than from the longitudinal muscles, and describe thus all the body with the veins and nerves.

[*Thinness of the colon in the old*]

The colon in the old becomes as slender as the middle finger of the hand, and in the young it is equal to the maximum breadth of the arm.

[*Retraction of the omentum in the old*]

The net which stands between the sifac and the intestines in the case of the old uncovers all these intestines of itself and withdraws between the bottom of the stomach and the upper part of the bowels.

Fogli B 22 v.

[*Spinal marrow and nerves*]

These two crusts which clothe the spinal marrow are the same as clothe the brain, that is, the pia and dura mater.

Vertebrae of the neck sawn through and removed from the middle in front, and the situation of the spinal marrow revealed and how it lives and ramifies outside these vertebrae.

[*Anatomical and functional relations between nerves and muscles*]

The substance of the spinal marrow enters for a certain distance within the origins of the nerves, and then follows the hollow nerve as far as its last ramifications; by which perforation it conveys sensation in each muscle, which muscle is composed of as many other very minute muscles as there are threads into which this muscle can be resolved; and each of the least of these muscles is wrapped up in almost imperceptible membranes into which the final ramifications of the before mentioned nerves become changed, for these obey in order to contract the muscle as they retire, and to cause it to expand again with each demand of the sensation which passes through the vacuity of the nerve. But to return to the spinal marrow, this is wrapped in two membranes of which only one clothes the pith-like substance of the spinal marrow, and in emerging from the hollow of vertebrae is transformed into nerve; the other clothes

the nerve, together with its principal branches, and ramifies together with each branch of the nerve, and thus forms the second cover of the spinal marrow, interposing itself between the bone of the vertebrae and the first membrane of this spinal marrow.

The spinal marrow is the source of the nerves which give voluntary movement to the limbs.

The pia and the dura mater clothe all the nerves which start from the spinal marrow.

Fogli B 23 r.

[*Precepts for the demonstration of the nerves of the arm*]

You will make a ramification of nerves with all their muscles attached.

And then you will make this ramification with the muscles attached to the nerves and to the bones which form the whole arm.

Here each nerve of the arm is joined with all the four nerves that issue from the spinal marrow.

Here will be shown all the muscles of the arm with the nerves and veins.

Make the man with arms open and showing all his nerves and their purposes according to the list; and you should use the greatest diligence with the reversive nerves in all their ramifications.

[*List of demonstrations of different parts of the human body*]

A demonstration of the peritoneum without the bowels.
A demonstration of bones cut through by the saw.
A demonstration of simple bones.
A demonstration of bones and nerves.
A demonstration of bones and veins.
A demonstration of nerves and muscles.
A demonstration of veins and muscles.
A demonstration of bones and intestines.
A demonstration of the mesentery.
A demonstration of limbs and muscles that interpret the spirit.
A demonstration of woman.
A demonstration of bones nerves and veins.
A demonstration of nerves alone.
A demonstration of bones alone.
A demonstration of nerves in bones that have been sawn through.
A demonstration of nerves in bones that are closed in.

A demonstration of bones and of the nerves which join themselves together, which nerves are extremely short, and those especially that join the vertebrae within.

Fogli B 23 v.

[*Precepts for the topographical demonstration of the upper limb and specially the hand*]

ORDER OF ANATOMY

Make first the bones, that is to say the arms, and show the motive power proceeding from the shoulder to the elbow in all its lines; then from the elbow to the arm; then from the arm to the hand, and from the hand to the fingers.

And in the arm you should show the movements of the fingers as they open; and these in their demonstration you will place alone.

In the second demonstration you will clothe these muscles with the second movements of the fingers; and you will do this stage by stage so as not to cause confusion; but first place upon the bones those muscles which join themselves with these bones without other confusion of other muscles, and with these you will place the nerves and veins which feed them, having first made the tree of the veins and nerves above the simple bones.

[*Of the nature of the teeth and their position and removal from the axis of their movements*]

That tooth has less power in gripping which is more remote from the centre of its movement. As if the centre of the movement of the teeth were *a* the axis of the jaw I say that in proportion as these teeth are more distant from this centre *a* they have less power in their grip; therefore *d e* is less powerful in its grip than the teeth *b c*; and from this follows the corollary which says:— that tooth is more powerful which is nearer to the centre of its movement or the axis of its movement; that is the grip of the teeth *b c* is more powerful than that of the teeth *d e*. (Nature made them less able to penetrate into food and with heavier points which are of greater power.) Therefore the teeth *b c* will have their points so much the more obtuse as they are moved by greater power; and for this reason the teeth *b c* will be more obtuse in proportion to the teeth *d e* when they are nearer the axis *a* of the jaws *a d* and *a e*; and for this reason nature has made the molars with large crowns to enable them to grind the food and not to penetrate it or cut it; and in front has made the teeth sharp

and penetrating and not suitable for grinding this food, and has made the eye teeth between the molars and the incisors.

Fogli B 24 r.

[*Reaction of pupil to stimulus of light, dilation and constriction*]

In the nocturnal animals the pupil proceeds to vary from a large to a larger size according to the great or greater obscurity of the night.

In these nocturnal animals the pupil also varies from a small to a smaller size according to the great or greater brightness of the day.

From what has been said one concludes that these nocturnal animals have always the same power of visual faculty in all the varieties of brightness or obscurity which can occur in times of day and of night.

The visual faculty is all in the whole pupil and all in each of its parts.

It follows that the half of the pupil sees the object in its entirety as if it was whole.

In proportion as the pupil is greater in quantity it will see its object as of greater shape and clearness; and thus conversely in proportion as it is less it will see this object as so much smaller and more obscure.

It follows that if one eye be closed the power of sight is diminished by half; and this may be proved with luminous bodies such as the sun the moon and the stars, and also with a light or fire.

This diminution of brightness may be observed without closing one of the eyes; but in lieu of closing it you must interpose the hand or the finger in front of one of the pupils between the air and the eye, and you will see with the two pupils a tract of air which will have the same boundary as the air seen by the one pupil alone, and that which is seen by one pupil will be just as much darker than that which is seen by two pupils. And the reason is as the diagram shows.

Fogli B 25 r.

[*Precepts for the topographical demonstration of the muscles of the back*]

You will make the rule and the measurement of each muscle and you will give the reason of all their functions, and the manner in which they use them and who moves them.

You will make first the spine of the back; then proceed to clothe it in stages, one above the other, of each of these muscles, and place the nerves and arteries and veins of each muscle by themselves, and in addition to this note to how many vertebrae they are joined, and which intestines are opposite to them, and what bones and other organic instruments.

The higher parts of the thin are higher in those who have well developed muscles, and similarly with fat ones; but the difference that there is between the shape of the muscles of those who are fat in comparison with those who have well developed muscles will be described here below.

Fogli B 27 r.

OF THE FUNCTION OF THE INTERCOSTAL MUSCLES

The three muscles which draw up the ribs we call the drawing muscles.

To the five [four?] muscles *c d e f* being created for the expansion of the breast we give the name of the expanding muscles.

The intercostal are the minute muscles interposed between the ribs which serve for the dilatation and attraction of those of these ribs; and these two so diametrically opposite movements are ordained for the purpose of collecting and breathing out the air in the lung which is enclosed in the region of the ribs; and the dilatation of these ribs proceeds from the external muscles of the ribs which are arranged as in the slant *m n* with the help of the three muscles *o p q*, which as they draw the ribs with great force upward extend their capacity in the manner that one sees done with the ventricles of the heart; but the ribs having to turn downwards would not of themselves be able to descend if the man remained lying down, if it were not for the internal muscles which have an opposite slant to the external muscles, which slant extends along the line *f n*.

OF THE POWER OF THE INTERCOSTAL [MUSCLES]

The function of the external intercostal muscles is to raise and expand the ribs and they are of admirable power in their position; seeing that they are established with their last upper extremities upon the same spine where begin the loose ribs, and their slant descends towards the navel.

Fogli B 27 v.

[*Of fingers and toes*]

Each protuberance formed by the joints of the toes and fingers has a hollow in the toes and fingers contiguous to it which receives within itself this roundness; and this nature has done in order not to render their width misshapen, seeing that if the said protuberances were in contact between them the feet would become of great width, and one of two

effects would also be necessary, that is that either the fingers would all be of the same length, or that one would have two joints and the other one as will be demonstrated concerning the bones, in its place.

HOW THE BODY OF THE ANIMAL CONTINUALLY DIES AND IS RENEWED

The body of anything whatsoever that receives nourishment continually dies and is continually renewed. For the nourishment cannot enter except in those places where the preceding nourishment is exhausted, and if it is exhausted it no longer has life. Unless therefore you supply nourishment equivalent to that which has departed, the life fails in its vigour; and if you deprive it of this nourishment, the life is completely destroyed. But if you supply it with just so much as is destroyed day by day, then it renews its life just as much as it is consumed; like the light of this candle formed by the nourishment given to it by the fat of this candle, which light is also continually renewed by swiftest succour from beneath, in proportion as the upper part is consumed and dies, and in dying becomes changed from radiant light to murky smoke. And this death extends for so long as the smoke continues; and the period of duration of the smoke is the same as that of what feeds it, and in an instant the whole light dies and is entirely regenerated by the movement of that which nourishes it; and its life receives from it also its ebb and flow, as the flicker of its point serves to show us. The same process also comes to pass in the bodies of the animals by means of the beating of the heart, whereby there is produced a wave of blood in all the veins, and these are continually either enlarging or contracting, because the expansion occurs when they receive the excessive quantity of blood, and the contraction is due to the departure of the excess of blood they have received; and this the beating of the pulse teaches us, when we touch the aforesaid veins with the fingers in any part whatsoever of the living body.

But to return to our purpose, I say that the flesh of the animals is made anew by the blood which is continually produced by that which nourishes them, and that this flesh is destroyed and returns by the mesaraic arteries and passes into the intestines, where it putrifies in a foul and fetid death, as they show us in their deposits and steam like the smoke and fire which were given as a comparison.

Fogli B 28 r.

OF THE MUSCLES WHICH MOVE THE TONGUE

No member needs so great a number of muscles as the tongue,—twenty four of these being already known apart from the others which I have discovered; and of all the members which are moved by voluntary action this exceeds all the rest in the number of its movements.

And if you shall say that this is rather the function of the eye, which receives all the infinite varieties of form and colour of the objects set before it, and of the smell with its infinite mixture of odours, and of the ear with its sounds, we may reply that the tongue also perceives an infinite number of flavours both simple and compounded; but this is not to our purpose, for our intention is to treat only of the particular movement of each member.

Consider carefully how by the movement of the tongue, with the help of the lips and teeth, the pronunciation of all the names of things is known to us; and how, by means of this instrument, the simple and compound words of a language arrive at our ears; and how these, if there were a name for all the effects of nature, would approach infinity in number, together with all the countless things which are in action and in the power of nature; and these would not be expressed in one language only, but in a great number of languages, and these also would tend to infinite variety, because they vary continually from century to century, and in one country and another, through the intermingling of the peoples, who by wars or other mischances are continually becoming mixed with each other; and these same languages are liable to pass into oblivion, and they are mortal like all the rest of created things; and if we grant that our world is everlasting we shall then say that these languages have been, and still must be, of infinite variety, through the infinite number of centuries which constitute infinite time.

Nor is this true in the case of any other sense; for these are concerned only with such things as nature is continually producing, and she does not change the ordinary kinds of things which she creates in the same way that from time to time the things which have been created by man are changed; and indeed man is nature's chiefest instrument, because nature is concerned only with the production of elementary things, but man from these elementary things produces an infinite number of compounds, although he has no power to create any natural thing except another like himself, that is his children. And of this the old alchemists will serve as my witnesses, who have never either by chance or deliberate

experiment succeeded in creating the smallest thing which can be created by nature; and indeed this generation deserves unmeasured praises for the serviceableness of the things which they have invented for the use of men, and would deserve them even more if they had not been the inventors of noxious things like poisons and other similar things which destroy the life or the intellect; but they are not exempt from blame in that by much study and experiment they are seeking to create, not, indeed, the meanest of nature's products, but the most excellent, namely gold, which is begotten of the sun inasmuch as it has more resemblance to it than to anything else that is, and no created thing is more enduring than this gold. It is immune from destruction by fire, which has power over all the rest of created things, reducing them to ashes, glass or smoke. If, however, insensate avarice should drive you into such error, why do you not go to the mines where nature produces this gold, and there become her disciple? She will completely cure you of your folly by showing you that nothing which you employ in your furnace will be numbered among the things which she employs in order to produce this gold. For there is there no quick-silver, no sulphur of any kind, no fire nor other heat than that of nature giving life to our world; and she will show you the veins of the gold spreading through the stone, — the blue lapis lazuli, whose colour is unaffected by the power of the fire.

And consider carefully this ramification of the gold, and you will see that the extremities of it are continually expanding in slow movement, transmuting into gold whatever they come in contact with; and note that therein is a living organism which it is not within your power to produce.

Fogli B 28 v.

OF THE MUSCLES WHICH MOVE THE LIPS OF THE MOUTH

The muscles which move the lips of the mouth are more numerous in man than in any other animal; and this order is a necessity for him on account of the many undertakings in which these lips are continually employing themselves, as in the four letters of the alphabet *b f m p*, in whistling, laughing, weeping and other actions like these. Also in the strange contortions used by clowns when they imitate faces.

WHAT MUSCLE IS THAT WHICH SO TIGHTENS THE MOUTH THAT ITS LATERAL BOUNDARIES COME NEAR TOGETHER?

The muscles which tighten the mouth lessening thus its length are in the lips themselves; or rather these lips are the actual muscles which close themselves. It is true that the muscle alters the position of the lip below the other muscles which are joined to it, of which one pair are those that distend it and move it to laughter; and that which contracts it is the same muscle of which the lower lip is formed, which restrains it by drawing in its extremities towards its centre; and the same process goes on at the same time with the upper lip; and there are other muscles which bring the lips to a point and others that flatten them, others are those which cause them to curl back, others that straighten them, others which twist them all awry, and others that bring them back to their first position; and so always there are found as many muscles as correspond to the various attitudes of these lips and as many others as serve to reverse these attitudes; and these it is my purpose here to describe and represent in full, proving these movements by means of my mathematical principles.

OF THE MOVEMENTS OF THE MUSCLES OF THE MOUTH WITH ITS LATERAL MUSCLES

There are many occasions when the muscles that form the lips of the mouth move the lateral muscles that are joined to them, and there are an equal number of occasions when these lateral muscles move the lips of this mouth, replacing it where it cannot return of itself, because the function of muscle is to pull and not to push except in the case of the genitals and the tongue. But if the contracting of the mouth draws back its lateral muscles equally this mouth will not of itself regain its lost length unless the said lateral muscles go back there; and if these lateral muscles extend the length of the mouth for the creation of laughter it is necessary for these lateral muscles to be drawn back by the contracting of the mouth when laughter ceases.

Fogli B 29 r.

[*Umbilical cord and vein*]

These four nerves have not in themselves any portion of blood; but when they enter the navel they become changed into a thick vein which then extends to the gate of the liver and goes ramifying through its

lower part, in which part each of its lowest ramifications ends and does not extend any higher.

Of the aforesaid four umbilical veins the outer pair form the sifac, the membrane adjacent to the peritoneum, and then bend downwards and end in the first ramification of the vein and the greater artery, which lies over the spine of the back.

The exterior ramification of the umbilical vein is enclosed between the first and the second membranes with which frequently the child is born.

[*Origin of the umbilical vein; its relation with the artery and its course*]

This umbilical vein is the origin of all the veins of the creature that is produced in the matrix, and it does not take its origin in any vein of the pregnant woman, because each of these veins is entirely separated and divided from the veins of the pregnant woman, and the veins and arteries are found together in pairs; and it is extremely rare for one to be found without the other being in company with it, and the artery is almost always found above the vein because the blood of the artery is the passage for the vital spirit, and the blood of the veins is that which nourishes the creature. And of these ramifications represented those which are raised up are ordained for the nourishment of the third thin membrane of the matrix, and the lower veins, set obliquely, are those which feed the last membrane which is contiguous to the animal that is clothed by it; and both the one and the other of these membranes often emerges, together with the creature, out of the matrix of the mother; and this occurs when the animal is not able to break it for then it emerges enveloped; and this is an easy thing, because these two extremely thin membranes as has been said above are not in any way connected with the said matrix which is also equipped with two membranes of considerable thickness, fleshy and covered with nerves.

Fogli B 29 v.

[*Intercostal muscles*]

CONCERNING THE NERVES THAT COMMUNICATE SENSATION TO THE INTERCOSTAL MUSCLES (MESOPLEURI)

The small muscles situated slantwise which descend from the upper part of the spine and terminate towards the Adam's apple derive their name from the pleura, and they are interposed between one rib and

another merely in order to contract the intervening spaces; and the nerves which communicate sensation to these muscles have their origin in the spinal marrow which passes through the backbone, and the lowest point at which they start in the spinal marrow is where the spine borders upon the reins.

Fogli B 30 r.

OF SPIRITS

We have just now stated that the definition of a spirit is a power united to a body, because of itself it can neither offer resistance nor take any kind of local movement; and if you say that it does in itself offer resistance, this cannot be so within the elements, because if the spirit is a quantity without a body, this quantity is what is called a vacuum, and the vacuum does not exist in nature, and granting that one were formed, it would be instantly filled up by the falling in of that element within which such a vacuum had been created. So by the definition of weight which says that gravity is a fortuitous power created by one element being drawn or impelled towards another, it follows that any element, though without weight when in the same element, acquires weight in the element above it, which is lighter than itself; so one sees that one part of the water has neither gravity nor levity in the rest of the water, but if you draw it up into the air then it will acquire weight, and if you draw the air under the water then the water on finding itself above this air acquires weight, which weight it cannot support of itself, and consequently its descent is inevitable, and therefore it falls into the water, at the very spot which had been left a vacuum by this water. The same thing would happen to a spirit if it were among the elements, for it would continually create a vacuum in whatsoever element it chanced to find itself; and for this reason it would be necessarily in perpetual flight towards the sky until it had passed out of these elements.

WHETHER THE SPIRIT HAS A BODY AMONG THE ELEMENTS

We have proved how the spirit cannot of itself exist among the elements without a body, nor yet move of itself by voluntary movement except to rise upwards. We now proceed to say that such a spirit in taking a body of air must of necessity spread itself through this air; for if it remained united, it would be separated from it and would fall, and so create a vacuum, as is said above; and therefore it is necessary,

if it is to be able to remain suspended in the air, that it should spread itself over a certain quantity of air; and if it becomes mingled with the air two difficulties ensue, namely that it rarefies that quantity of air within which it is mingled, and consequently this air, becoming rarefied, flies upwards of its own accord, and will not remain among the air that is heavier than itself; and moreover, that as this aetherial essence is spread out, the parts of it become separated, and its nature becomes modified, and it thereby loses something of its former power. To these there is also added a third difficulty, and that is that this body of air assumed by the spirit is exposed to the penetrating force of the winds, which are incessantly severing and tearing in pieces the connected portions of the air, spinning them round and whirling them amid the other air; and therefore the spirit which was spread through this air would be dismembered or rent in pieces and broken, together with the rending in pieces of the air within which it was spread.

WHETHER THE SPIRIT HAVING ASSUMED A BODY OF AIR CAN MOVE OF ITSELF OR NO

It is impossible that the spirit diffused within a quantity of air can have power to move this air; and this is shown by the former section in which it is stated that the spirit rarefies that quantity of air within which it has entered. This air consequently will rise up above the other air, and this will be a movement made by the air through its own levity, and not through the voluntary movement of the spirit; and if this air meets the wind, by the third part of this section this air will be moved by the wind and not by the spirit which is diffused within it.

WHETHER THE SPIRIT CAN SPEAK OR NO

Wishing to prove whether or no the spirit can speak, it is necessary first to define what voice is, and how it is produced, and we may define it as follows:— the voice is movement of air in friction against a compact body, or of the compact body in friction against the air, which is the same thing; and this friction of compact with tenuous substance condenses the latter, and so makes it capable of resisting; moreover, the tenuous substance, when in swift motion, and a similar substance moving slowly, condense each other at their contact, and make a noise or tremendous uproar; and the sound or murmur caused by one tenuous substance moving through another at a moderate pace [is] like a great flame

which creates noises within the air; and the loudest uproar made by one tenuous substance with another is when the one swiftly moving penetrates the other which is unmoveable, as for instance the flame of fire issuing from the cloud, which strikes the air and so produces thunderbolts.

We may say therefore, that the spirit cannot produce a voice without movement of air, and there is no air within it, and it cannot expel air from itself if it has it not, and if it wishes to move that within which it is diffused it becomes necessary that the spirit should multiply itself, and this it cannot do unless it has quantity. And by the fourth part it is said that no tenuous body can move unless it has a fixed spot from whence to take its motion, and especially in the case of an element moving in its own element, which does not move of itself, except by uniform evaporation at the centre of the thing evaporated, as happens with a sponge squeezed in the hand, which is held under water, since the water flows away from it in every direction with equal movement through the openings that come between the fingers of the hand within which it is squeezed.

Of whether the spirit has articulate voice, — and whether the spirit can be heard, — and what hearing is, and seeing; — and how the wave of the voice passes through the air, — and how the images of objects pass to the eye.

Fogli B 31 r. and 30 v.

[*Skull and vertebral column*]

If nature had added the muscle *a c* in order to bend the head towards the shoulder it would have been necessary that the spinal column of the neck should bend as the bow bends by reason of its cord; consequently nature in order to avoid this inconvenience created the muscle *a b* which draws down the side of the skull *a* with a slight bending of the bone of the neck, because the muscle *a b* draws the side of the skull *a* towards *b*, the root of the spinal column of the neck, and as the skull is fixed on a small axis above the front of the bone of the neck it bends very readily to right and left without there being too much curve of the bone of the neck.

Fogli B 32 r.

[*Precepts for demonstration of vessels of the neck and their importance for the life*]

But make this demonstration from three different aspects, namely in front, at the side and behind.

If you tighten the four veins on each side where they are in the throat he whose veins are pressed will suddenly fall on the ground asleep and as though dead, and will never wake of himself; and if for the hundredth part of an hour he is left in this condition he will never wake any more either of himself or by the help of others.

[*with drawing*]

a are ramifications of arteries.

b is the ramification of the veins.

c is the cephalic vein.

n are two veins which enter into the vertebrae of the neck in order to nourish them.

o is the basilical vein.

S are the apoplectic veins.

Fogli B 32 v.

[*Trachea. Œsophagus. Stomach*]

How the rings of the trachea do not join for two reasons; the one is because of the voice, and the other is in order to allow space for the food between these and the bone of the neck.

[*Wandering nerve and its function, and varied structure of the brain*]

Note in what part the left reversive nerve turns, and what function it serves.

And note the substance of the brain whether it is thinner or thicker above the starting of the nerves than in its other parts; and see in what manner the reversive nerves communicate sensation to the rings of the trachea, and which muscles are those that give the movement to these rings in order to produce the voice deep, medium or shrill.

The reversive nerves start in *a b*, and *b f* is the reversive nerve that descends to the door-keeper of the stomach, and its companion the left nerve descends to the case that encloses the heart, and I believe this to be the nerve that enters into the heart.

[*The heart a muscle nourished like the others by arteries and veins*]

The heart in itself is not the beginning of life; but it is a vessel formed of thick muscle, vivified and nourished by the artery and vein as are the other muscles. True it is that the blood and the artery which purges itself in it are the life and nutriment of the other muscles, and it is of such density that fire can hardly injure it; and this is seen in the case of

men who have been burnt, in whom after the bones have been burnt to cinders the heart within still bleeds; and nature has made this great capacity of resistance to heat so that it may be able to resist the great heat generated in the left side of the heart by means of the blood of the artery which becomes attenuated in this ventricle.

The variation of the voice starts from the dilatation and contraction of the rings of which the trachea is composed; dilatation which is produced by the muscles which join with these rings; and the contraction is produced I believe by itself because it is formed of cartilage which bends of its own accord in order to return to the shape first given to it.

Fogli B 33 v.

[*Varying relation of size of artery and vein of neck*]

Note whether the artery is thicker than the vein, or the vein than the artery, and do the same with children, young people and old ones males and females and creatures of the earth air and water.

Fogli B 34 r.

[*Origin of all the veins of the gibbous part of the heart*]

The root of all the veins is in the gibbous part of the heart, that is of the skin of the blood; and this is manifest because there it is thicker than elsewhere, and goes on ramifying an infinite number of times through every limb of the creature.

[*Veins from the liver to the spleen and their function*]

Of the two thick veins which go from the liver to the spleen, which come from the larger veins of the spine, I think that these are amassers of the superfluous blood, which being every day evacuated by the mesaraic veins is deposited in the bowels, causing the same stench when it has reached there that arises from the dead in the sepulchres, and that is the stench of the excrements.

[*With figure*]

Ramification made by the navel and the vein and the artery in the gate of the liver.

Represent first all the ramifications of the veins which come to the gate of the liver, all together, and then each by itself separately in three or if you prefer four demonstrations; I said three because the vein and the artery make the same journey.

Fogli B 34 v.

[*The olfactory and optic nerves and their relations*] [*With figures*]

a b c d are the nerves that convey odours.

The nerves start from the last membrane which clothes the brain and the spinal marrow.

e n nerves are the optic nerves which are situated below the nerves called caruncular; but the optic serve the visual faculty and the caruncular the olfactory.

[*Process for examination of the brain and the basilar nerves*]

You will take to pieces the substance of the brain as far as the confines of the dura mater which is interposed between this basilar bone and the substance of the brain; then note all the places where this dura mater penetrates the basilar bone, with the nerves clothed by it together with the pia mater; and this knowledge you will acquire with certainty whenever by diligence you raise this pia mater little by little, commencing with the extremities, and noting from one part to another the position of the before mentioned perforations, commencing first at the right or left side, representing this in its entirety; and then you will follow the opposite part, which will give you knowledge as to whether the foregoing is well situated or no, and it will also bring you to an understanding of whether the right part is similar to the left part; and if you find that it varies you will look again in the other anatomies whether this variation is universal in all men and women.

Note where the exterior parts meet the interior parts.

Fogli B 35 r.

[*Preparation of the hæmorrhoidal veins*]

Cut the subject in the middle of the spine; but first bind the chyle (vein) and artery, so that it may not pour out, and thus you will be able to see the hæmorrhoidal veins in halves, that is in each division of this subject.

OF THE FOOD WHICH MAKES CORRUPTION

I say that the extremities of the mesaraic veins which attract to themselves the substance of the food enclosed in the intestines are enlarged by means of the natural heat of the man, because the heat separates and enlarges and the cold assembles and constricts; but this would not be sufficient if to this heat were not added the stench formed by the corruption of the blood returned by the arteries to these intestines, which

blood acts in these intestines not otherwise than it does in bodies that have been buried; which stench enlarges the intestines and penetrates into all the interstices and swells and puffs out the bodies in the shape of casks; and if you should say that this stench arose from the heat in the bodies this would not be found to be the case with the inflated bodies which are covered with snow, and the power of the stench is much more active and multiplies much more than does that of the heat.

Fogli B 36 v.

DEMONSTRATION OF THE BLADDER OF THE MAN

[*Reins, ureters, bladder and urethra*]

First demonstration

Of these three demonstrations of bladders, in the first are represented the ureteral pores and how they part from the reins *L h*, and join together at the bladder two fingers space above the starting point of the neck of this bladder, and at a short distance on the inside of this meeting point these pores discharge the urine into the bladder, from *p b* into *n f*, in the manner that is shown in part in the channel *S*, whence it is then poured through the pipe of the penis *a g*.

It remains for me in this case to represent and describe the position of the muscles which open and close the passage of the urine to the mouth of the neck of this bladder.

Second demonstration

In the second demonstration one represents the four ramifications namely right and left of the veins that feed this bladder, and the right and left artery which gives it life, that is spirits.

And the vein is always situated above the artery.

Third demonstration

In the third demonstration is contained how the vein and artery surround the beginning of the ureteral pore *m n* in the position *n*, and there is shown the interlacing of the ramification of the vein with the ramification of the artery.

[*Entry of the urine into the bladder*]

The urine, after departing from the kidneys, penetrates in the ureteral pores, and from these passes into the bladder, near the centre of its height, entering into this by means of small perforations made

transversely between one coat and another; and this slanting perforation was not made because nature doubted whether this urine could return to the kidneys, because this is impossible by the fourth [rule] concerning channels (de' condotti) where it is stated: — 'the water which from a height descends by a thin vein and penetrates under the bottom of the sheet of water cannot be compared as to its reflex movement, unless there is as great thickness in the sheet of water as the thickness of the descending vein, nor any greater height of water in this than the depth in the sheet of water.' And if you were to say that the more the bladder fills the more it closes, to this one will reply that the fact of such perforations being pressed together by the urine which closed these walls would prevent the entrance of the rest of the urine as it descends, which cannot be by the fourth mentioned previously, which states that the thin raised-up urine is more potent than the low and wide which is in the bladder.

Fogli B 37 r.

You will make this demonstration.

Trachea, whence the voice passes.

Œsophagus (meri), whence passes the food.

Nerves (ipopletiche), whence pass the vital spirits.

Backbone, where the ribs begin.

Vertebrae, whence start the muscles which terminate in the nape of the neck and raise the face towards the sky.

[*Precepts for the demonstration of the intestines*]

Describe all the heights and breadths of the intestines, and measure them by fingers in halves and thirds of fingers of a dead man's hand, and for all put at what distance they are from the navel the breasts or the flanks of the dead.

[*The relation of the lungs to the bronchial tubes*]

The substance of the lung is expansible and extendible, and it is interposed between the ramifications of the trachea, so that these ramifications may not be dislodged from their positions; and this substance interposes itself between this ramification and the ribs of the chest, after the fashion of a soft feather bed.

Remember to represent the mediastinum (heart cavity) with the case of the heart, with four demonstrations, from four aspects, in the manner that is written below.

[How to describe the thoracic organs]

Make first the ramification of the lung, and then make the ramification of the heart, that is of its veins and arteries; afterwards make the third ramification of the mixture of the one ramification with the other; and these mixtures you will make from four aspects, and you will do the like with the said ramifications which will be twelve; and then make a view of each from above and one from below, and this will make in all eighteen demonstrations.

You will first make this lung in its entirety, seen from four aspects, in its entire perfection; afterwards you will represent it so that it is seen perforated merely with the ramification of its trachea in four other aspects.

After you have done this do the same in the demonstration of the heart, first entire, and then with the ramification of its veins and arteries.

Afterwards you will make it seen from four aspects how the veins and arteries of the heart mingle with the ramification of the trachea; then make a ramification of nerves alone from four aspects, and then weave them in four other aspects of the heart and lung joined together; and observe the same rule with the liver and spleen, kidneys, matrix and testicles, brain, bladder and stomach.

Fogli B 37 v.

[Description of the region of the mouth]

Here the lips become muscles, moving the lateral muscles with themselves.

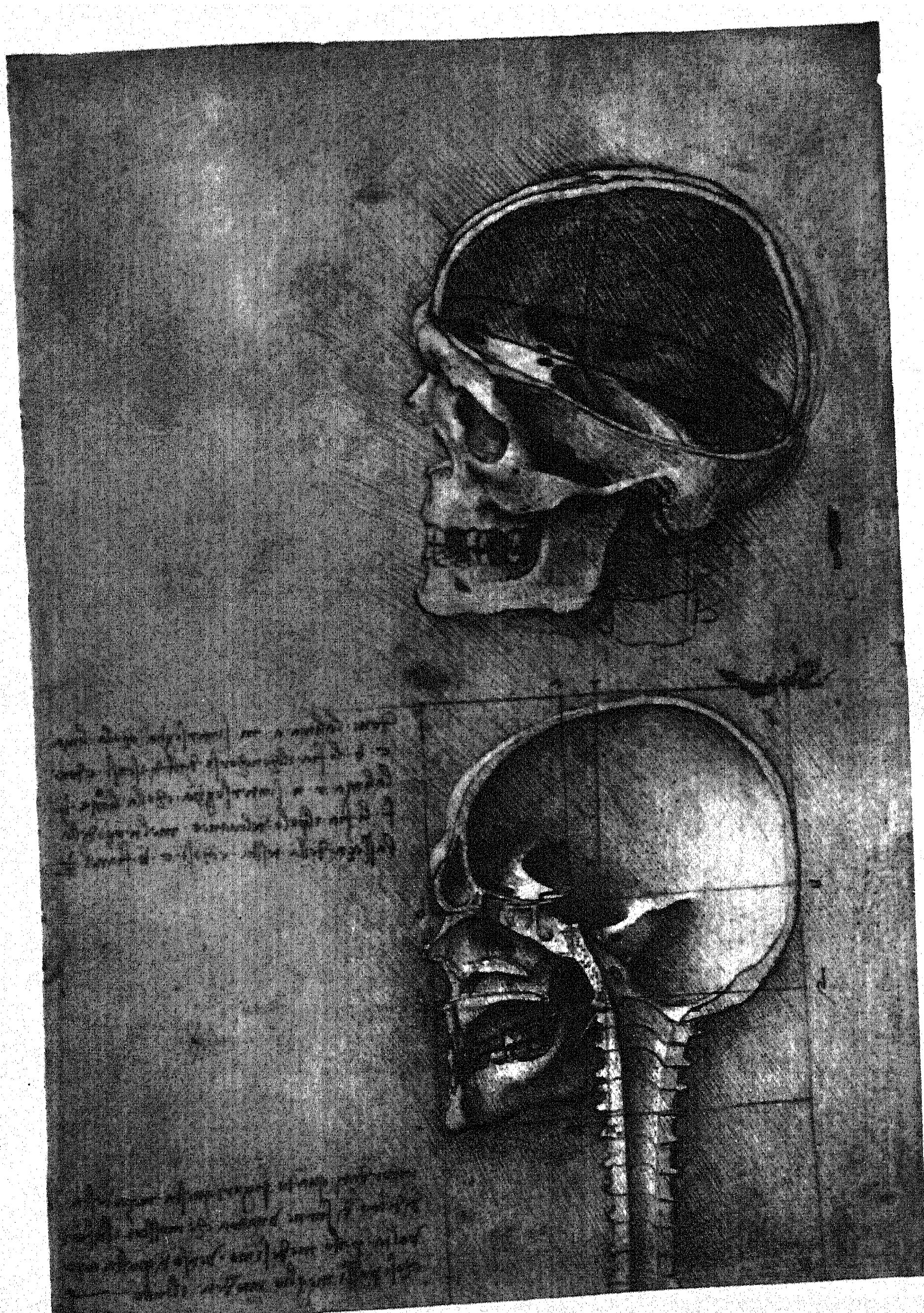
And then the lateral muscles move the lips.

It is necessary to note first as to the bones of the face, in what part arise and whence come the nerves which first open and then close the lips of the mouth, and where the muscles are attached which are penetrated by these nerves.

[Nerves and muscles of the mouth and their functions in various movements]

The nerve *n m* in the lower lip and the nerve *o p* in the upper lip are the cause why the mouth closes with the help of the muscles of which these lips of the mouth are formed.

The muscles called lips of the mouth as they become compressed towards their centre draw the lateral muscles after them; and as the lateral muscles draw back in themselves, contracting, they then draw back the lips of the mouth and so this mouth expands.



SKULL IN MEDIAN SECTION

Royal Library, Windsor

[Text : I. 163]

The final contraction of the mouth makes it equal to half what it is when it is at its greatest extension, and it is the same with regard to the greatest breadth of the nostrils of the nose and of the interval interposed between the tear-ducts of the eyes.

OF THE NERVES WHICH TIGHTEN THE LIPS

The movements that the lips make as they tighten are two, of which one is that which presses and strains the one lip against the other, the second movement is that which compresses or shortens the length of the mouth; but that which presses the one lip against the other does not proceed beyond the last molars of the mouth, and these when they are drawn are of such great power that, keeping the teeth somewhat open, they would draw the lips of the mouth within the teeth, as is shown in the mouth *g h* which is drawn by the muscles *r* by its sides.

[*Which muscles are those that tighten the mouth across?*]

The muscles that tighten the mouth across as is shown above are the lips themselves, which draw the sides of the mouth towards the centre; and this is shown us by the fourth [rule] of this which says: — the skin which forms the covering of the muscles that draw always points with its wrinkles to the spot where is the cause of the movement; and by the fifth: no muscle uses its power in pushing but always in drawing to itself the parts that are joined to it; therefore the centre of the muscles called the lips of the mouth draws to itself the extremities of this mouth with part of the cheeks, and for this reason the mouth in this function is always filled with wrinkles.

Fogli B 38 v.

[*How to describe the cranium*]

Where the line *a m* intersects the line *c b* there will be the meeting place of all the senses; and where the line *r n* intersects the line *h f* there will be the axis of the cranium in the third of the divisions of the head.

Remember when you represent this half head from the inside to make another which shall show the outside turned in the same direction as this, so that you may better apprehend the whole.

Fogli B 40 r.

[*Orbital cavities (The antrum of Highmore)*]

I wish to take away that part of the bone, the support of the cheek, which is found within the four lines *a b c d*, and to show through the

opening revealed the breadth and depth of the two cavities which hide behind it.

In the cavity above is hidden the eye, the instrument of sight, and in that below is the humour which nourishes the roots of the teeth.

The cavity of the bone of the cheek resembles in depth and breadth the cavity which receives the eye within it, and in capacity it is very similar to it and receives veins within it by the holes *m* which descend from the brain passing through the passage which discharges the excess of the humours of the head in the nose.

Other perceptible holes are not found in that of the cavity above which surrounds the eye. The hole *b* is where the visual faculty passes to the sense, the hole *n* marks the spot at which tears rise from the heart to the eye, passing by the channel of the nose.

Fogli B 40 v.

[*Cavity of the cranium. Seat of the concourse of all the senses and its relations*]

The concourse of all the senses has below it in a perpendicular line the uvula where one tastes the food at a distance of two fingers, and it raises itself above the tube of the lung and above the orifice of the heart for the space of a foot; and it has the junction of the bone of the cranium half a head above it; and it has before it in a horizontal line at a third of a head away the tear-duct of the eyes; and behind it it has the nape of the neck at two thirds of a head and on the sides the two pulses of the temples at equal distance and height. The veins which are shown within the cranium in their ramification produce an imprint of the half of their thickness in the bone of the cranium, and the other half is hidden in the membranes which clothe the brain; and where the bone has a dearth of veins within it is replenished from without by the vein *a m*, which after having issued forth from the cranium passes into the eye and then in the . . .

Fogli B 41 r.

[*Cavities of the face and their relation*]

The cavity of the socket of the eye and the cavity of the bone that supports the cheek, and that of the nose and of the mouth are of equal depth, and end below the seat of the senses[1] in a perpendicular line.

And each of these cavities has as much depth as the third part of a man's countenance, that is from the chin to the hair.

[1] MS. il senso comune.

[*The different kinds of teeth and their function*]

Six upper molars have three roots each and they have two roots in the outer side of the jaw and one in the inner side, and the two last of these are cut in two or four years or thereabouts.

Next come four premolars of two roots each, one on the inside and outside of the jaw, then follow the two maestre (canines) with only one root, and in front are the four teeth which do the cutting and have one root only.

The lower jaw has also sixteen teeth as above; but its molars have only two roots; the other teeth are as those in the upper jaw; in animals the teeth of which there are two fasten on the prey, the four cut it up, the six grind it.

Fogli B 41 v.

ON THE SECOND DAY OF APRIL 1489 THE BOOK ENTITLED 'OF THE HUMAN FIGURE'

[*Veins of the face*]

The vein *m* is raised up and enters under the bone of the cheek, and through the hole of the socket of the eye passes between the under side of the eyeball and the bone that supports it, and in the middle of the said passage this vein pierces the bone, and drops down half a finger's space, having pierced through the surface of the bone under the edge of the socket *n* mentioned above; there it commences to raise itself up, and after marking for some distance the edge of the eye passes from the tear-duct and finally within the eyelids after having raised itself for a space of two fingers, and there commences the ramification which spreads through the head.

Fogli B 42 r.

[*Various themes in anatomy and physiology*]

What nerve is the cause of the eye's movement and makes the movement of one eye draw the other?

Of closing the eyelids.

Of raising the eyebrows.

Of lowering the eyebrows.

Of shutting the eyes.

Of opening the eyes.

Of raising the nostrils.

Of parting the lips with teeth clenched.

Of bringing the lips to a point.

Of laughing.

Of wondering.

Set yourself to describe the beginning of man when he is created in the womb.

And why an infant of eight months does not live.

What sneezing is.

What yawning is.

Epilepsy.

Spasm.

Paralytic.

Trembling from cold.

Perspiration.

Fatigue.

Hunger.

Sleep.

Thirst.

Sensuality.

Of the nerve which is the cause of the movement from the shoulder to the elbow.

Of the movement that is from the elbow to the hand.

From the wrist to the beginning of the fingers.

From the beginning of the fingers to the middle of them.

And from the middle to the last joint.

Of the nerve which is the cause of the movement of the thigh.

And from the knee to the foot and from the ankle to the toes.

And so to their centres.

And of the turning movement of this leg.

Fogli B 42 v.

[*How nature gives animals the power of motion*]

ON MACHINES

Why nature cannot give the power of movement to animals without mechanical instruments, as is shown by me in this book on the works of movement which nature has created in the animals. And for this reason I have drawn up the rules of the four powers of nature without which nothing through her can give local movement to these animals. We shall therefore first describe this local movement and how it produces and is produced by each of the other three powers. Then we shall describe the natural weight, for though no weight can be said to be other

than accidental, it has pleased us to style it thus in order to distinguish it from the force which in all its operations is of the nature of weight and is for this reason called accidental weight, and this is the force which is produced by the third power of nature, that is, the inherent or natural power. The fourth and last power will be called percussion, that is, the end or restraint of movement. And we shall begin by stating that every local insensible movement is produced by a sensible mover, just as in a clock the counterpoise is raised up by man who is its mover. Moreover the elements repel or attract each other, for one sees water expelling air from itself, and fire entering as heat under the bottom of a boiler and afterwards escaping in the bubbles on the surface of the boiling water. And again the flame draws to itself the air, and the heat of the sun draws up the water in the form of moist vapour which afterwards falls down in thick heavy rain. Percussion however is the immense power of things which is generated within the elements.

Quaderni I I r.

[*Description of the human body in process of dissection*]

THE ORDER OF THE BOOK

This plan of mine of the human body will be unfolded to you just as though you had the natural man before you. The reason is that if you wish to know thoroughly the parts of a man after he has been dissected you must either turn him or your eye so that you are examining from different aspects, from below, from above and from the sides, turning him over and studying the origin of each limb; and in such a way the natural anatomy has satisfied your desire for knowledge. But you must understand that such knowledge as this will not continue to satisfy you on account of the very great confusion which must arise from the mixture of membranes with veins, arteries, nerves, tendons, muscles, bones and the blood which of itself tinges every part with the same colour, the veins through which this blood is discharged not being perceptible by reason of their minuteness. The completeness of the membranes is broken during the process of investigation of the parts which they enclose, and the fact that their transparent substance is stained with blood prevents the proper identification of the parts which these cover on account of the similarity of the blood-stained colour, for you cannot attain to any knowledge of the one without confusing and destroying the other.

Therefore it becomes necessary to have several dissections: you will

need three in order to have a complete knowledge of the veins and arteries, destroying all the rest with very great care; and three others for a knowledge of the membranes, 'panniculi', three for the tendons, muscles and ligaments, three for the bones and cartilages, three for the anatomy of the bones, for these have to be sawn through in order to show which are hollow and which not, which are full of marrow, which spongy, which thick from the outside inwards, and which thin. And some have great thinness at one part and thickness at another, and at another part they are hollow or filled with bone or full of marrow, or spongy. Thus it may be that all these conditions will sometimes be found in the same bone and there may be another bone which has none of them. Three also must be devoted to the female body, and in this there is a great mystery by reason of the womb and its foetus.

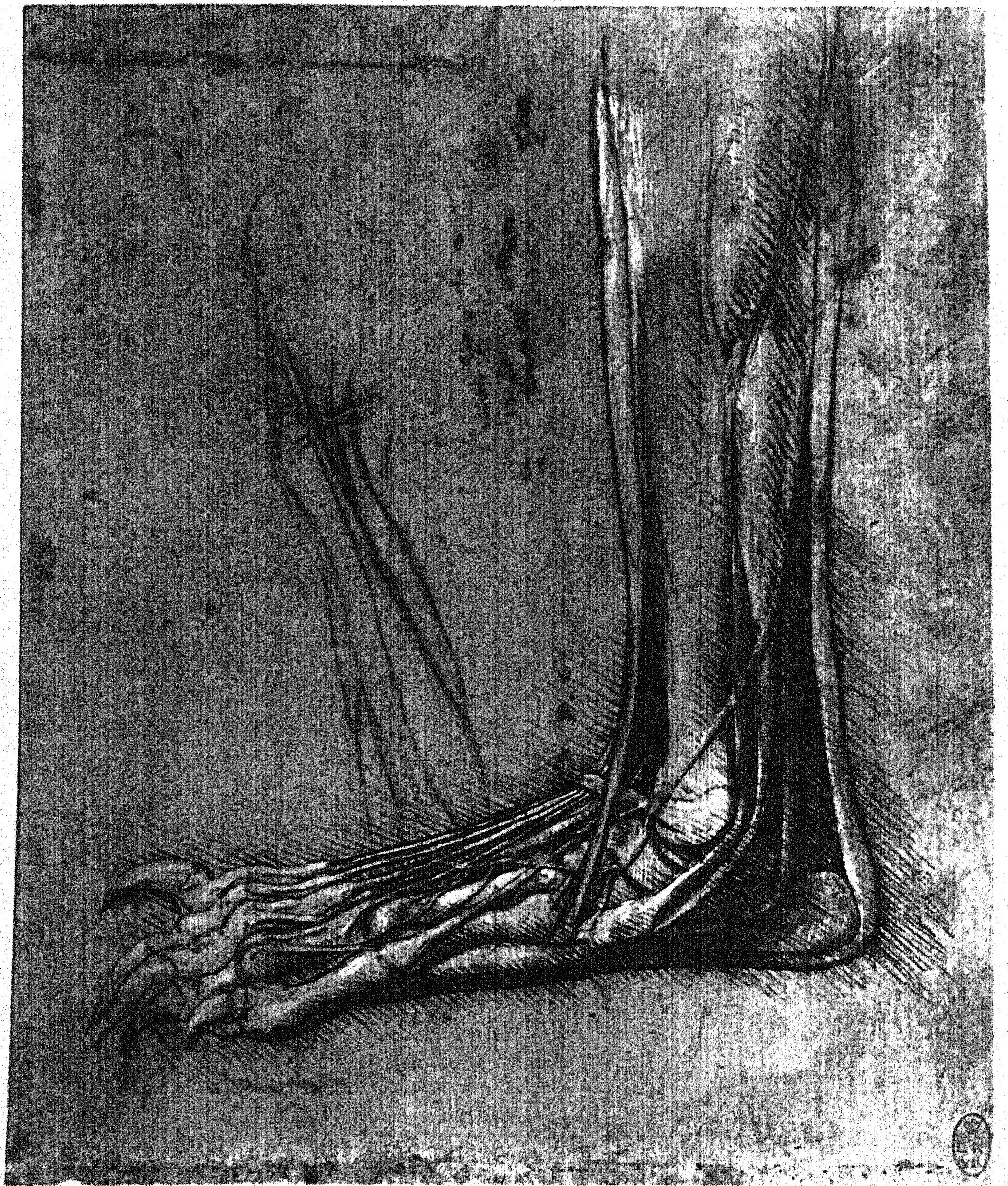
Therefore by my plan you will become acquainted with every part and every whole by means of a demonstration of each part from three different aspects; for when you have seen any member from the front with the nerves, tendons and veins which have their origin on the opposite side, you will be shown the same member either from a side view or from behind, just as though you had the very member in your hand and went on turning it from side to side until you had a full understanding of all that you desire to know.

And so in like manner there will be placed before you three or four demonstrations of each member under different aspects, so that you will retain a true and complete knowledge of all that you wish to learn concerning the figure of man.

Therefore there shall be revealed to you here in fifteen entire figures the cosmography of the 'minor mondo' (the microcosmos or lesser world) in the same order as was used by Ptolemy before me in his Cosmography. And therefore I shall divide the members as he divided the whole, into provinces, and then I shall define the functions of the parts in every direction, placing before your eyes the perception of the whole figure and capacity of man in so far as it has local movement by means of its parts.

And would that it might please our Creator that I were able to reveal the nature of man and his customs even as I describe his figure!

And I would remind you that the dissection of the nerves will not reveal to you the position of their ramification nor into which muscles they ramify by means of bodies dissected either in flowing water or in



STUDY FOR MONSTER: HUMAN FOOT WITH BEAR'S CLAWS

Royal Library, Windsor

[Text: I. 169]

lime water; because, although the origin of their derivation may be discerned without the use of the water as well as with it, their ramifications tend to unite in flowing water all in one bunch just as does flax or hemp carded for spinning, so that it becomes impossible to find out again into which muscles the nerves are distributed or with which or how many ramifications they enter the said muscles.

[*Dissection of the human hand*]

OF THE HAND FROM WITHIN

When you begin the hand from within first separate all the bones a little from each other so that you may be able quickly to recognise the true shape of each bone from the palmar side of the hand, and also the real number and position of each, and have some sawn through down the centre of their thickness, that is lengthwise, so as to show which is empty and which full. And having done this place the bones together at their true contacts and represent the whole hand from within wide open. Then set down the complete figures of the first ligaments of the bones. The next demonstration should be of the muscles which bind together the wrist and the remainder of the hand. The fifth shall represent the tendons which move the first joints of the fingers. The sixth the tendons which move the second joints of the fingers. The seventh those which move the third joints of these fingers. The eighth shall represent the nerves which give them the sense of touch. The ninth the veins and the arteries. The tenth shall show the whole hand complete with its skin and its measurements, and measurements should also be made of the bones. And whatever you do for this side of the hand you should do the same for the other three sides, that is from the palmar or under side, from the dorsal side and from the sides of the extensor and the flexor muscles.

And thus in the chapter on the hand you will make forty demonstrations; and you should do the same with each member.

And in this way you will attain complete knowledge.

You should afterwards make a discourse concerning the hands of each of the animals, in order to show in what way they vary, as with the bear, in which the ligaments of the tendons of the toes are joined above the neck of the foot.

Quaderni I 2 r.

Not abbreviators but forgetters (obbliatori) should they be called who abridge such works as these.

Quaderni I 4 r.

Make a discourse on the censure deserved by scholars who put obstacles in the way of those who practise anatomy and by the abbreviators of their researches.[1]

[*Nothing superfluous or lacking in nature*]

Nothing is superfluous and nothing is lacking in any species of animal or product of nature unless the defect comes from the means which produce it.

Quaderni I 4 v.

IF THE WIND WHICH ESCAPES FROM THE TRACHEA CONDENSES ITSELF IN ITS TRANSIT OR NO

All the air that enters into the trachea is of equal quantity in all the degrees which are produced by its ramification; after the manner of the branches born during the seasonal growth of the plants which every year, if the various thicknesses of all the branches that have been produced are reckoned together, equal the thickness of the stem of their plant.

But the trachea contracts itself in the larynx in order to condense the air, which seems a thing of life as it comes from the lung to create the various kinds of voices, and also to press and dilate the different passages and ventricles of the brain, because if the trachea were thus dilated at its upper end as it is in the throat, the air would not be able to condense itself and perform the duties and benefits which are necessary to life and to man, that is in speaking, singing and the like. And the wind which is suddenly expelled from the lung as it produces the deep sighs proceeds by the help of the wall of the abdomen (mirac?) which squeezes the intestines, and they raise the diaphragm that presses on the lung.

Quaderni I 5 v.

IF THE HEART AT ITS DEATH CHANGES POSITION OR NO

The change of the heart at its death is similar to the change which it undergoes during the expulsion of its blood, and is somewhat less.

[1] There may be a veiled significance in the use of the word 'abbreviatori' as the term was also applied to the secretaries at the Chancery of the Vatican. Leonardo in one of his letters complains of having been impeded in his anatomical researches as a result of information laid before the Pope.

This is shown when one sees the pigs in Tuscany, where they pierce the hearts of the pigs by means of an instrument called a borer, which is used for drawing wine out of casks. And thus turning the pig over and tying it up well they pierce its right side and its heart at the same time with the borer, thrusting it in in a straight line. And if this borer pierces the heart when it is distended the heart as it expels the blood becomes contracted and draws the wound to the top together with the point of the borer; and the more it raises the point of the borer within the more it lowers the handle of the borer outside; and afterwards when the heart is distended and drives this wound downwards the part of this borer which is outside makes a movement that is the opposite to that of the part within which moves together with the movement of the heart. And this it does many times, so that at the end of life that part of the borer that is outside remains in the middle of the two extremities, where were the last contrary movements of the heart when it was alive. And when the heart becomes quite cold it shrinks somewhat and contracts as much as it had extended when warm because heat causes a body to increase or diminish when it enters into it or leaves it; and this I have seen many times and have observed such measurements having allowed the instrument to remain in the heart until the animal was cut up. . . .

And from the greatest to the smallest movement of the heart of this animal is about the thickness of a finger, and at the end the heart remains with its point out of its usual position by about half the thickness of a finger; and pay attention lest you make a mistake in taking this measurement because sometimes the handle of this borer will not make any change whether the heart is living or dead; and this occurs when the heart receives its wound half way in the process of its contracting, in which position it remains when it is dead. And sometimes this handle makes the greater change and this occurs when the heart receives its wound during its period of greater or less length, and thus it will make as many varieties of distances as are the variations in the length or shortness of the heart when it is wounded. Moreover this handle will make greater or less changes according as the point of the borer penetrates further or less into the heart; for if the point of the iron transfixes the heart it makes a lesser movement from the centre of its movement, that is from the place, than it would do if the iron had only wounded the heart in the front part of its anterior wall; and on this point I will not dwell further because a complete treatise on these movements

has been compiled in the twentieth book on the forces of the lever. And if you should consider that when the heart had been transfixed the length of the borer could not follow the movement spoken of above through it being impeded by the anterior wall of the heart you must understand that in the extension and dilation of the heart, it draws or drives the point of this iron along with its motion; and the iron which finds itself in the anterior wall enlarges its wound both upwards and downwards, or to put it better moves it seeing that the roundness of the thick part of the iron does not enlarge since it does not cut, but carries with it the front wound of the heart, compressing the part of the heart in contact with it now from the upper part of the wound, now from the lower part, and such rarefaction and compression is easily made by this heart when it is warm because it is less dense. Quaderni I 6 r.

[*Notes on anatomy*]

You should make the liver in the embryo differing from that of man, that is with the right and left parts equal.

But you should make first the anatomy of the hatched eggs.

Say how at four months the child is half the length and so is one eighth the weight that it will be at birth.

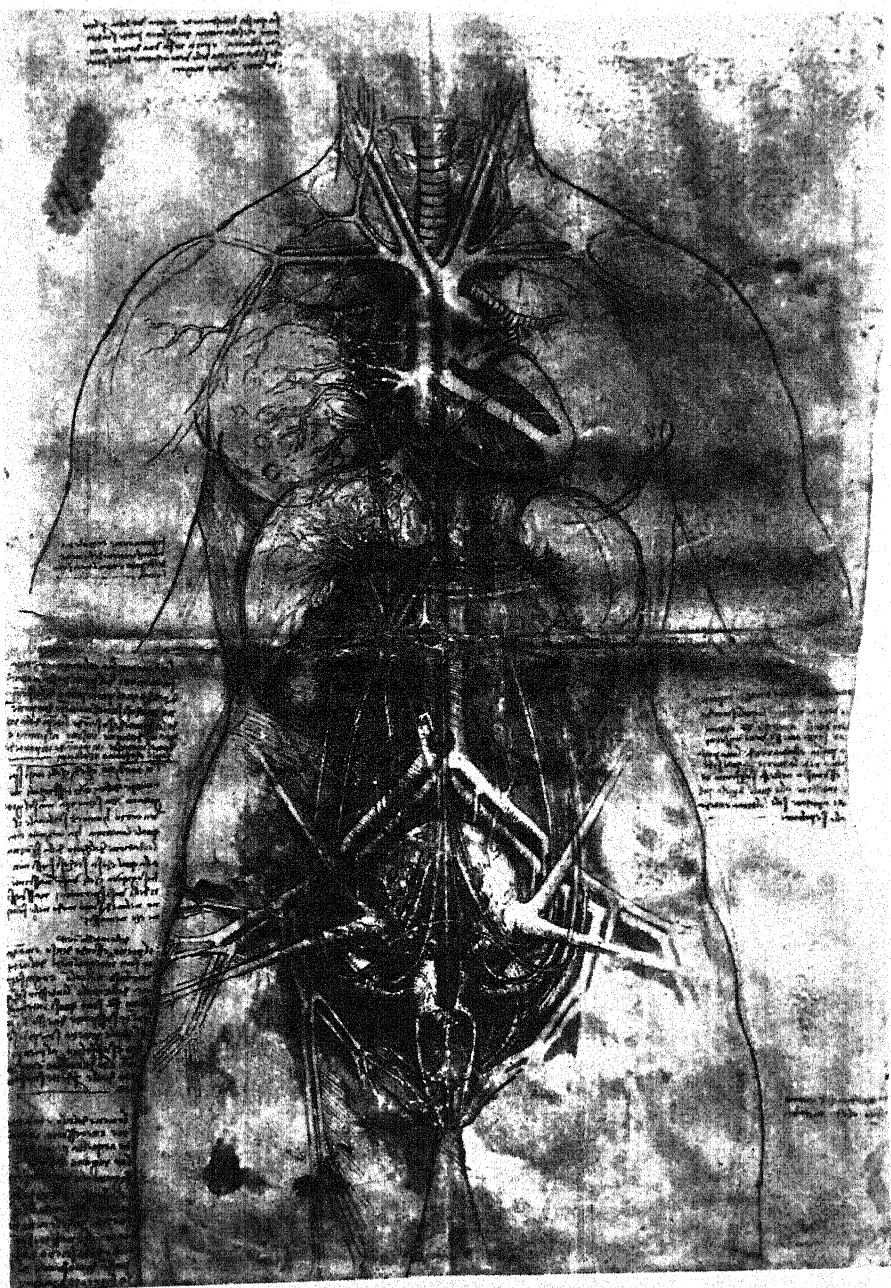
Describe which and how many are the muscles that move the larynx in the production of the voice. Quaderni I 10 r.

[*Development of embryo*]

Do this demonstration also as seen from the side, in order to give information how much one part may be behind the other; and then do one from behind in order to give information as to the veins covered by the spine and by the heart and greater veins.

Your order shall commence with the formation of the child in the womb, saying which part of it is formed first and so on in succession, placing its parts according to the times of pregnancy until the birth, and how it is nourished, learning in part from the eggs which hens make. Quaderni I 12 r.

And you who say that it is better to look at an anatomical demonstration than to see these drawings, you would be right, if it were possible to observe all the details shown in these drawings in a single figure, in which, with all your ability, you will not see nor acquire a knowledge of



FRONT OF FEMALE FIGURE SHOWING PRINCIPAL ORGANS

Royal Library, Windsor

[Text: I. 172]

more than some few veins, while, in order to obtain an exact and complete knowledge of these, I have dissected more than ten human bodies, destroying all the various members, and removing even the very smallest particles of the flesh which surrounded these veins, without causing any effusion of blood other than the imperceptible bleeding of the capillary veins. And as one single body did not suffice for so long a time, it was necessary to proceed by stages with so many bodies as would render my knowledge complete; and this I repeated twice over in order to discover the differences.

But though possessed of an interest in the subject you may perhaps be deterred by natural repugnance, or, if this does not restrain you, then perhaps by the fear of passing the night hours in the company of these corpses, quartered and flayed and horrible to behold; and if this does not deter you then perhaps you may lack the skill in drawing essential for such representation; and even if you possess this skill it may not be combined with a knowledge of perspective, while, if it is so combined, you may not be versed in the methods of geometrical demonstration or the method of estimating the forces and strength of muscles, or perhaps you may be found wanting in patience so that you will not be diligent.

Concerning which things, whether or no they have all been found in me, the hundred and twenty books which I have composed will give their verdict 'yes' or 'no'. In these I have not been hindered either by avarice or negligence but only by want of time. Farewell.

Quaderni I 13 v.

[*Drawings describe natural things better than words*]

[*Note at side of drawing of heart showing the arrangement of the veins and arteries*]

With what words O writer can you with a like perfection describe the whole arrangement of that of which the design is here?

For lack of due knowledge you describe it so confusedly as to convey but little perception of the true shapes of things, and deceiving yourself as to these you persuade yourself that you can completely satisfy the hearer when you speak of the representation of anything that possesses substance and is surrounded by surface.

I counsel you not to cumber yourself with words unless you are speaking to the blind. If however notwithstanding you wish to demonstrate in words to the ears rather than to the eyes of men, let your speech

be of things of substance or natural things, and do not busy yourself in making enter by the ears things which have to do with the eyes, for in this you will be far surpassed by the work of the painter.

How in words can you describe this heart without filling a whole book? Yet the more detail you write concerning it the more you will confuse the mind of the hearer. And you will always then need commentators or to go back to experience; and this with you is very brief, and has to do only with a few things as compared with the extent of the subject concerning which you desire complete knowledge.

Quaderni II 1 r.

[*Praise of the Creator in anatomy*]

[*Drawing of action of the muscles of the heart, followed by descriptive note in which occurs the sentence:*]

This the Inventor made for the cause shown in the figure above, which reveals how the Creator does not make anything superfluous or defective.

Quaderni II 3 r.

[*Anatomy of neck — Praise of the Creator*]

Each of the vertebrae of the neck has ten muscles joined to it.

You should show first the spine of the neck with its tendons like the mast of a ship with its shrouds without the head; then make the head with its tendons which give it its motion upon its axis.

a b are muscles which keep the head upright, and so do those which originate in the clavicle, *c b*, joined to the pubes by means of the longitudinal muscles.

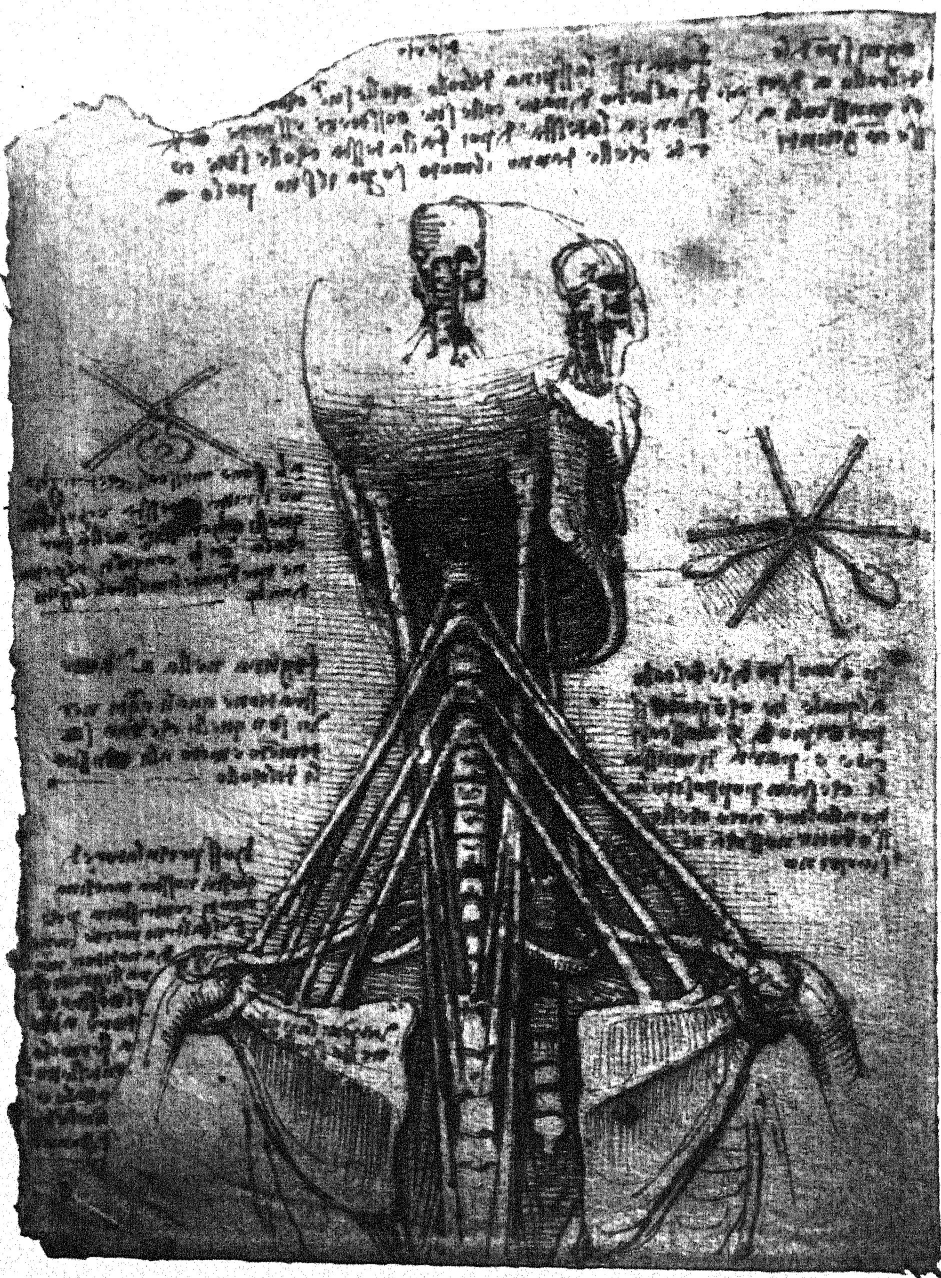
Show in the second demonstration which and how many are the nerves that give sensation and movement to the muscles of the neck.

n is one of the vertebra of the neck to which is joined the beginning of three muscles, that is of three pairs of muscles which are opposite each other, so that the bone where they have their origin may not break.

O speculator concerning this machine of ours let it not distress you that you impart knowledge of it through another's death, but rejoice that our Creator has ordained the intellect to such excellence of perception.

Quaderni II 5 v.

Why the heart does not beat nor the lung breathe during the time that the child is in the womb which is filled with water; for if it should draw a breath it would instantly be drowned. But the breathing and the



ANATOMY OF NECK

Royal Library, Windsor

[Text: I. 174]

beating of its mother's heart works in the life of the child which is joined to her by means of the umbilical cord as it works in the other members.

Therefore during every harmonic or as you may say musical tempo the heart makes three movements, as is contained below, of which tempos an hour contains one thousand and eighty. The heart therefore moves three thousand five hundred and forty times in each hour in the process of opening and shutting. And it is this frequency of movement which warms the thick muscles of the heart, and this heat warms the blood that continually beats within it. It heats it more in the left ventricle, where the walls are very thick, than in the right ventricle with the thin wall. And this heat makes the blood grow thinner and turns it to vapour and changes it into air, and would change it to elemental fire, if it were not that the lung renders help at this crisis with the coolness of its air.

But the lung cannot send air into the heart, nor is this necessary since, as has been said, air is generated in the heart, and this, as it becomes mingled with the warm thick moisture, evaporates through the extremities of the capillary veins at the surface of the skin in the form of perspiration; and moreover the air which is breathed in by the lung, enters continually dry and cold, and issues forth moist and warm. But the arteries which are joined by continual contact to the network of branches of the trachea, spreading through the lung, are what catches the coolness of the air as it enters into this lung. Quaderni II 11 r.

[*Balance of heart in man and animals*]

And if you say that the left external wall (of the heart) has been made thick in order that it might acquire greater weight, so that it should make a counterpoise to the right ventricle, which has a great weight of blood, you have not reflected that this balancing was not necessary, seeing that all the land animals except man have the heart in a recumbent position; and the heart of man also lies thus when he is lying in his bed. But you would not be weighing the matter well in your conclusion, because the heart has two supports which descend from the collar bone, from which by the fourth of 'De Ponderibus' the heart is not able to balance itself, if there is not a single support above, and these two supports are the Arteria Aorta and the Vena cava; and furthermore if the heart is deprived of the weight of the blood as it

becomes restricted and gives it in deposit to its upper ventricles, the centre of gravity of the heart would then be on the right side of the heart and thus its left side would be lightened. But this theory of balancing is not a true one as was said above because the animals which lie or which stand on four feet have the heart lying as they are themselves, and with these no balancing of the heart is sought.

And in the case of the bat which when it sleeps always places itself upside down, how does the heart balance with the right and left ventricle?

Quaderni II 17 r.

WHY THE PRINCIPAL VALVES OF THE RIGHT VENTRICLE ARE MADE WITH SO LITTLE MEMBRANE AND SUCH A NETWORK OF CORDAE

This thing was ordained by nature in order that as the right ventricle commences to shut, the escape of the blood from its huge capacity should not suddenly cease, because a portion of that blood had to be given to the lung, and it would not be given if the valve had stopped the exit. But this ventricle shut itself when the lung had received its quantity of blood and so [from] the right ventricle it was able to press through the pores of the median wall into the left [MS. right] ventricle; and at the same time the right auricle became the depositary of the excess of the blood which it passes to the lung, and this suddenly gives it to the opening of this right ventricle restoring itself through the blood with which the liver supplies it.

HOW MUCH BLOOD IS THE LIVER ABLE TO GIVE IT THROUGH THE OPENING OF THE HEART?

It restores as much of it as it consumes; that is a minimum part, because in an hour the heart opens about two thousand times. There is great weight.

The right ventricle was made heavier than the left one in order that the heart may stand in a slanting direction; and when the blood rises out of the left ventricle and lightens it this blood goes from it towards the left side with the centre of its gravity when it is in the upper ventricles.

The heart has four ventricles, that is two upper ones called auricles of the heart, and two lower than these called the right and left ventricles.

Quaderni II 17 v.

[*Definitions*]

Definition of the instruments.

Discourse on the nerves, muscles, tendons, 'panniculi' (membranes) and ligaments.

The function of the nerves is to convey sensation; they are the team of drivers of the soul, for they have their origin from its seat and command the muscles so that they move the members at the consent of the will of this soul.

The muscles the ministers of the nerves draw to themselves the sinews which are joined to these members in a similar manner.

The tendons are mechanical instruments which have no sensation of themselves but carry out as much work as is entrusted to them.

The membranes (panniculi) are joined to the flesh being interposed between the flesh and the nerve, and most frequently they are joined to the cartilage.

The ligaments are joined to the tendons and are of the nature of membranes (panniculi) which bind together the joints of the bones and are converted into cartilage, and they are as many in number at every joint as are the tendons which move the joint and as are the tendons opposite to these which come to the same joint, and these ligaments join and mingle together, helping strengthening and connecting one with another.

The cartilage is a hard substance, like, let us say, hardened tendon or softened bone, and its position is always between the bone and the tendon because it partakes of both substances, and it is flexible and unbreakable, the flexibility acting in it like a spring.

Pellicles are certain muscular parts which are made up of flesh, tendons and nerves, the union of these forming a composition which is capable of being extended in any direction; flesh is a mixture made up of muscles, tendon, nerve, blood and artery.

Bone is a hardness, inflexible, adapted for resistance, and is without sensation and terminates in the cartilages which form its extremities; and its marrow is composed of sponge, blood, and soft fat coated over with a very thin tissue. The sponge-like substance is a mixture of bone, fat and blood.

The membranes (panniculi) are of three kinds, that is, made up of tendons, made up of nerves, and made up of nerves and tendons; and the mixed membrane is woven of tendon, nerve, muscle, vein and artery.

The membranes that are between the tendons and the cartilages are so formed as to unite tendon with cartilage in a large and continuous joint so that it may not break through excess of force; and when the

muscle itself thickens it does not draw to itself the tendon or any member, but the muscle is drawn by the tendon towards the membrane and the cartilage, as happens with the muscles inside the ventricles of the heart when they shut their openings. But the muscles of the other members are drawn towards the bone where they are joined, and draw their tendon behind them together with the member that is joined to this tendon.

The tears come from the heart and not from the brain.

Define all the parts of which the body is composed, commencing with the skin with its outer coating which often detaches itself through the action of the sun.

Quaderni II 18 v.

[*Six constituent parts of movement*]

There are six things which take part in the composition of the movements; namely bone, cartilage, membrane, tendon, muscle and nerve, and these six consequently are in the heart.

Quaderni II 23 r.

[*With sectional drawing 'in congressu'*]

I reveal to men the origin of their second — first or perhaps second — cause of existence.

Through these figures will be shown the cause of many dangers of ulcers and diseases.

Division of the spiritual from the material parts.

And how the child breathes and how it is nourished through the umbilical cord; and why one soul governs two bodies, as when one sees that the mother desires a certain food and the child bears the mark of it.

And why the child [born] at eight months does not live.

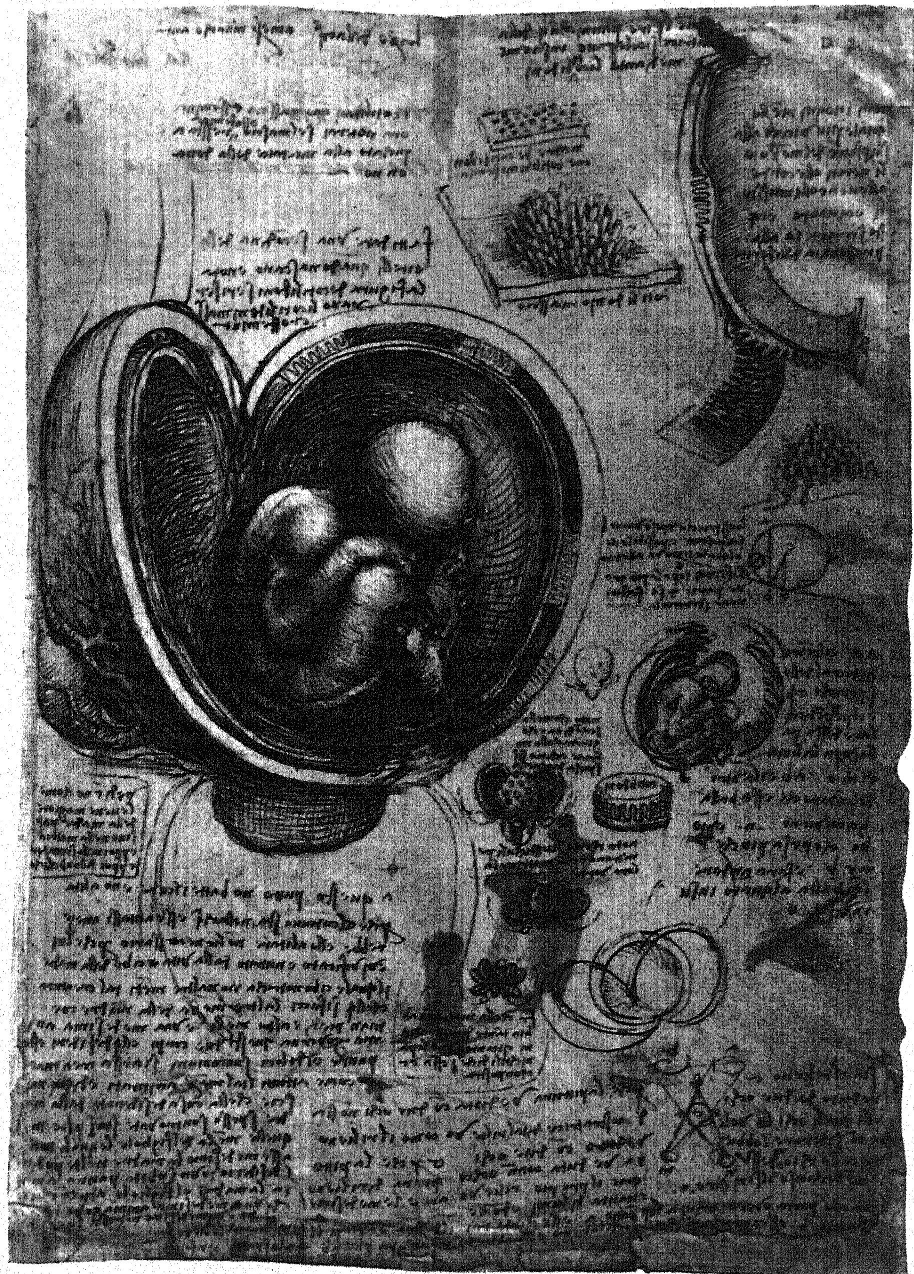
Here Avicenna contends that the soul gives birth to the soul and the body to the body and every member, but he is in error.

Quaderni III 3 v.

The child does not draw breath in the body of its mother because it lies in water, and whoever breathes in water is immediately drowned.

Whether the child while within the body of its mother is able to weep or to produce any sort of voice or no.

The answer is no; because it does not breathe neither is there any kind of respiration; and where there is no respiration there is no voice.



CHILD IN WOMB

Royal Library, Windsor

[Text: I. 179]

Ask the wife of Biagino Crivelli how the capon rears and hatches the eggs of the hen when he is in the mating season.

They hatch the chickens by making use of the ovens by the fireplace.

Those eggs which are of a round form will be cockerels and the long-shaped ones pullets.

Their chickens are given into the charge of a capon which has been plucked on the under part of its body, and then stung with a nettle and placed in a hamper. When the chickens nestle underneath it it feels itself soothed by the sensation of warmth and takes pleasure in it, and after this it leads them about and fights for them, jumping up into the air to meet the kite in fierce conflict.

Quaderni III 7 r.

Book 'On the Water' to Messer Marco Antonio.[1]

[*With drawing of child in womb*]

In the case of this child the heart does not beat and it does not breathe because it lies continually in water. And if it were to breathe it would be drowned, and breathing is not necessary to it because it receives life and is nourished from the life and food of the mother. And this food nourishes such creature in just the same way as it does the other parts of the mother, namely the hands feet and other members. And a single soul governs these two bodies, and the desires and fears and pains are common to this creature as to all the other animated members. And from this it proceeds that a thing desired by the mother is often found engraved upon those parts of the child which the mother keeps in herself at the time of such desire; and a sudden fear kills both mother and child.

We conclude therefore that a single soul governs the bodies and nourishes the two [bodies].

Quaderni III 8 r.

[*How one mind governs two bodies*]

As one mind governs two bodies, in as much as the desires the fears and the pains of the mother are one with the pains that is the bodily pains and desires of the child which is in the body of the mother, in like manner the nourishment of the food serves for the child and it is

[1] Marco Antonio della Torre. Context shows that text refers to presence of water in uterus during gestation.

nourished from the same cause as the other members of the mother, and its vital powers are derived from the air which is the common living principle of the human race and of other living things.

[*Colour of skin due to parents—seed of mother as potent as that of father*]

The black races in Ethiopia are not the product of the sun; for if black gets black with child in Scythia, the offspring is black; but if a black gets a white woman with child the offspring is grey. And this shows that the seed of the mother has power in the embryo equally with that of the father.

Quaderni III 8 v.

[*On sheet with drawings and notes of foetus in uterus*]

See how the birds are nourished in their eggs.

Quaderni III 9 v.

[*Representation of lungs with bronchiae and vessels*]

When you represent the lung make it perforated so that it may not obstruct what is behind it, and let the perforation be all the ramifications of the trachea and the veins of the artery (aorta) and of the vena cava and then outside these draw a contour line round about them to show the true shape, position and extent of this lung.

Quaderni III 10 r.

[*With drawings of action of lungs*]

Represent first all the ramification which the trachea makes in the lung and then the ramification of the veins and arteries separately, and then represent everything together. But follow the method of Ptolemy in his Cosmography in the reverse order: put first the knowledge of the parts and then you will have a better understanding of the whole put together.

Quaderni III 10 v.

[*With drawing*]

This is the lung in its case.

The question arises where the lung becomes cooler or more heated, and the same is searched for in the heart.

It has to be ascertained whether the wall of the heart interposed between its two ventricles is thinner or thicker as the heart becomes longer or shorter, or one may say as it expands or contracts.

It is our opinion that during the process of dilation it increases its

capacity and the right ventricle draws blood from the liver and the left ventricle at such time draws blood from the right one.

As many times as the pulse beats so many times does the heart expand and contract.

Quaderni IV 3 r.

[*Of the muscles*]

No one can move others if he does not move himself.

Quaderni IV 5 r.

[*Relation of reversive nerves to heart and brain. Seat of soul. Origin of vital powers. Action of heart. Relation of movement of heart and lung*]

Follow up the reversive nerves as far as the heart, and observe whether these nerves give movement to the heart or whether the heart moves of itself. And if its movement comes from the reversive nerves which have their origin in the brain then you will make it clear how the soul has its seat in the ventricles of the brain, and the vital powers derive their origin from the left ventricle of the heart. And if this movement of the heart originates in itself then you will say that the seat of the soul is in the heart and likewise that of the vital powers, so that you should attend well to these reversive nerves and similarly to the other nerves, because the movement of all the muscles springs from these nerves which with their ramifications pour themselves into these muscles. Many are the times when the heart draws into itself some of the air which it finds in the lung, and returns it after it is heated without this lung having gathered other air from outside.

It is proved that it must of necessity be as is here set forth, and this is that the heart which moves of itself only moves in opening and shutting itself; this opening and shutting creates motion along the line that lies between the cusp and the base or corona of the heart; and it cannot open without drawing into itself air from the lung, which it immediately blows out again into the lung, where it will afterwards be seen that this lung will be restored by a vigorous movement of sudden deep breathing from the new refreshment of cold air; and this occurs when a fixed purpose of the mind banishes into oblivion the respiration of the breath.

In closing itself the heart with its nerves and muscles draws behind it the powerful vessels which proceed from the heart to unite with the lung; and this is the principal cause of the opening of the lung, because

it cannot open unless the vacuum increases, and the vacuum cannot acquire any increase unless it refills itself, and finding the air more suitable for this restoration of the vacuum it refills itself with it. This heart afterwards as it contracts comes to reopen itself, and as it reopens itself it relaxes the drawn-out nerves and vessels of the lung, from which it follows that the lung closes itself up again and at the same time restores the increase in the vacuum of the heart through the wind which it blows out of itself, and in part sends out of the mouth the superfluous air for which neither in it nor in the heart is there any capacity.

Quaderni IV 7 r.

[*Subcutaneous vessels in the groin and armpit*]

From the inner parts of the arms and of the thighs go veins that form branches from their main stems and these run all over the body between the skin and the flesh.

And remember to note where these arteries part company from the veins and the nerves.

Quaderni IV 8 r.

[*Tonsils*]

The two tonsils are formed on the opposite sides of the base of the tongue and are in the shape of two small cushions interposed between the bone of the maxilla and the base of the tongue so as to create a space between the two, so that on one side it may be capable of receiving the lateral roundness of the convex formation of the tongue caused by it bending, and may with its convex part wipe away the food from the angle of the maxilla round the lateral parts of the base of the tongue.

Twenty-eight muscles in the roots of the tongue.

[*Of tongues*]

[*Leonine and bovine species*]

This is the reverse of the tongue [*drawing*], and its surface is rough in many animals and especially in the leonine species, such as lions, panthers, leopards, lynxes, cats and the like which have the surface of their tongues very rough as though they were covered with very small nails, somewhat flexible; and when they lick their skin these nails penetrate down to the roots of the hairs, and after the fashion of combs they carry away the minute animals which feed upon them.

And I once saw how a lamb was licked by a lion in our city of Florence, where there are always from twenty five to thirty of them and

they bear young. With a few strokes of his tongue the lion stripped off the whole fleece with which the lamb was covered, and having thus made it bare he ate it; and the tongues of the bovine species are also rough.

Quaderni IV 9 v.

[*Pronunciation of vowels*]

The membrane interposed between the passage that the air makes in part through the nose and in part through the mouth is the only one which man uses in order to pronounce the letter *a*, that is the membrane *a n*, and though the tongue and lips may do what they can, this will never prevent the air which streams out from the trachea from forming the sound *a* while in this concavity *a n*. Moreover *u* is formed at the same place with the help of the lips which tighten and thrust themselves out a little; and the more these lips thrust themselves out the better do they pronounce the letter *u*. True it is that the epiglottis *m* rises somewhat towards the palate.

And if it were not for it doing thus, the *u* would be changed into *o*, and this *o* . . .

And whether when *a o u* are pronounced distinctly and rapidly it is necessary that in pronouncing them continuously without any interval of time the opening of the lips should go on continually contracting, that is that in pronouncing *a* they should be wide apart, closer together in pronouncing *o* and much closer still in pronouncing *u*.

It is proved how all the vowels are pronounced with the back part of the movable palate which covers the epiglottis; and moreover such pronunciation comes from the position of the lips by means of which a passage is formed for the air as it streams out carrying with it the created sound of the voice, which even when the lips are closed streams out through the nostrils, but when issuing through such passage will never become a demonstrator of any of these letters.

From such an experiment one may conclude with certainty that the trachea does not create any sound of vowel but that its office only extends to the creation of the aforesaid voice and especially in *a o u*.

[*The muscles of the tongue*]

The tongue is found to have twenty-four muscles which correspond to the six muscles of which the mass of the tongue which moves in the mouth is composed.

The present task is to discover in what way these twenty-four muscles are divided or apportioned in the service of the tongue in its necessary movements, which are many and varied; and in addition to this it has to be seen in what manner the nerves descend to it from the base of the brain, and in what manner they pass into this tongue distributing themselves and breaking into ramifications. And it must further be noted how and in what manner the said twenty-four muscles convert themselves into six in the formation they make in the tongue. And furthermore you should show whence these muscles have their origin, that is in the vertebrae of the neck at the contact with the oesophagus, and some in the maxilla on the inside, and some on the trachea on the outside and laterally. And similarly how the veins nourish them and how the arteries give them the spiritus, (and how the nerves give them sensation).

Moreover you shall describe and represent in what way the procedure of varying and modulating and articulating the voice in singing is a simple function of the rings of the trachea moved by the reversive nerves, and in this case no part of the tongue is used.

And this is proved by what I have proved before, that the pipes of the organ do not become deeper or sharper through the change of the fistula (that is that place in which the voice is produced), in making it wider or narrower; but only through the change of the pipe to be wide or narrow or long or short as is seen in the expansion or compression of the winding trumpet, and also in the pipe which is of fixed width or length, the sound varies according as the wind is let into it with greater or less impetus. And this amount of variation is not found in the case of objects struck with a greater or less blow, as is perceived when bells are struck by very small or very large clappers; and the same thing occurs with pieces of artillery similar in width but differing in length, but in this case the shorter piece makes a louder and deeper noise than the longer one. And I do not go into this at greater length because it is fully treated in the book about harmonical instruments. And for this reason I will resume my discourse concerning the functions of the tongue where I left it.

The tongue works in the pronunciation and articulation of the syllables which are the constituent parts of all words. This tongue is also employed during the necessary revolutions of the food in the process of mastication and in the cleansing therefrom of the inside of the mouth

together with the teeth. Its principal movements are seven; namely stretching out, drawing together and drawing back, thickening, shortening, spreading out and pointing; and of these seven movements three are composite because one cannot be created without another also being created joined to it of necessity; and this is the case with the first and the second, that is with stretching out and drawing together, for you cannot stretch out a substance which is capable of being expanded without it contracting and straightening itself on all its sides. And a similar result occurs in the third and fourth movements which are contrary to the two first, that is in the thickening and shortening.

After these come the fifth and sixth movements which together form its third movement made up of three movements, namely spreading out pointing and shortening.

Although human subtlety makes a variety of inventions answering by different means to the same end, it will never devise an invention more beautiful more simple or more direct than does nature, because in her inventions nothing is lacking, and nothing is superfluous; and she needs no countervailing weights when she creates limbs fitted for movement in the bodies of the animals, but puts within them the soul of the body which forms them, that is the soul of the mother which first constructs within the womb the shape of the man, and in due time awakens the soul that is to be its inhabitant. For this at first remained asleep, in the guardianship of the soul of the mother, who nourishes and gives it life through the umbilical vein, with all its spiritual members; and so it will continue for such time as the said umbilical cord is joined to it by the secundines and the cotyledons by which the child is attached to the mother. And this is the reason why any wish or intense desire or fright experienced by the mother, or any other mental suffering, is felt more powerfully by the child than by the mother, for there are many cases in which the child loses its life from it.

This discourse does not properly belong here, but is necessary in treating of the structure of animated bodies; and the rest of the definition of the soul I leave to the wisdom of the friars, those fathers of the people who by inspiration know all mysteries. I speak not against the sacred books, for they are supreme truth.

Quaderni IV 10 r.

HERE FOLLOWS [CONCERNING] THE ARTICULATION OF THE HUMAN VOICE

The extension and restriction of the trachea together with its dilation and contraction are the cause of the variation of the voice of the animals from high to deep and from deep to high; and as regards the second of these actions, as the shortening of the trachea is not sufficient when the voice is raised it dilates itself somewhat towards the top part, which does not receive any degree of sound but produces a raising of the voice of this remnant of the shortened pipe. But of this we shall make an experiment in the anatomy of the animals, by pumping air into their lungs and compressing them, and so narrowing and dilating the fistula which produces their voice.

Quaderni IV 10 v.

Here is a doubt as to the pannicles which close up the blood in the antechamber of the heart that is in the base of the aorta, whether nature could have dispensed with them or no, since one may clearly see how the three walls or hinges where such pannicular valves of the heart are established, are those which by their swelling shut this blood out from the heart when the heart reopens on the side below these valves.

And this last closing nature carries out in order that the great force which the heart employs in this left ventricle, as it reopens in order to draw into itself the blood that percolates through the narrow interstices of the wall that divides it from the left ventricle, should not for the restoring of the vacuum be obliged to draw with it the most delicate pannicles of the said valves of the heart.

The revolution of the blood in the antechamber of the heart, the base of the aorta, serves two effects, of which the first is that this revolution multiplied in many aspects causes great friction in itself, and this heats and lightens the blood and increases and vivifies the spiritus vitales which always maintain themselves in warmth and moisture. The second effect of this revolution of the blood is to close up again the opened gates of the heart with a complete system of fastening with its first reflex movement.

As many as are the times which this gate expels the blood so many are those which the heart beats, and for this reason those who are feverish become inflamed.

Quaderni IV 11 r.

Between the cords (cordae) and threads of the muscles of the right ventricle there are interwoven a quantity of minute threads of the nature and shape of the minute muscles which form the worm in the brain and of those which weave the rete mirabile; and these wind themselves round the most minute and imperceptible nerves and weave themselves with them. And these muscles are in themselves very capable of expansion and contraction, and they are situated within the fury of the rush of the blood, which passes in and out among the minute cords of the muscles before they are converted into the membranes (panniculi) of the valves.

Before you open the heart inflate the ventricles of the heart commencing from the artery of the aorta; and then tie them up and consider their size. Afterwards do the same with the right ventricle or the right 'orecchio'; and by so doing you will see its shape and its purpose, for it was created in order to expand and contract and so cause the blood to revolve as it passes through its cells which are full of tortuous passages divided by rounded walls without any angles, in order that the motion of the blood not finding any angular obstructions may have an easier revolution in its eddying course. And thus it comes to warm itself with so much more heat in proportion as the movement of the heart is the more rapid. So it sometimes attains to such great heat that the heart is suffocated; and I have already seen one case where it was burst as a man was fleeing before his enemies, and he poured out perspiration mingled with blood through all the pores of his skin; and this heat forms the spiritus vitales. And thus heat gives life to all things; as one sees the heat of the hen or of the turkey-hen giving life and growth to the chickens, and as the sun in returning causes all the fruits to blossom and burgeon.

Quaderni IV 13 r.

[*Division of surface of heart by vessels. Peeling the flesh off to find certain vessels*]

The heart has its surface divided into three parts by three veins which descend from its base, of which veins two terminate the extremities of the right ventricle and have two arteries in contact below them. As regards the third vein I have not yet seen whether it has an artery with it, and consequently I am about to remove some of the flesh of the surface in order to satisfy myself. But the surface space of the heart enclosed within its arteries occupies half the surface circle of the thickness of the heart and forms the outer wall of the right ventricle.

[*Heating by churning, and by the action going on in the heart*]

Observe whether when butter is being made the milk as it revolves becomes heated; and by such means you will be able to prove the efficacy of the ventricles of the heart, which receive and expel the blood from their cavities and other passages, as made only in order to heat and refine the blood and make it more suitable for penetrating the wall through which it passes from the right to the left ventricle, where by means of the thickness of its wall, that is of that of the left ventricle, it conserves the heat which this blood brings to it.

Quaderni IV 13 v.

[*Tendons*]

Describe the tendons of any limb from four aspects and how they are diffused through the muscles, and how the muscles produce the tendons and the tendons the joints etc.

Quaderni IV 15 r.

[*The tree of the vessels (with drawing)*]

ANATOMY OF THE VESSELS

Here shall be represented the tree of the vessels generally, as Ptolemy did with the universe in his Cosmography; then shall be represented the vessels of each member separately from different aspects.

Make the view of the ramification of the vessels from behind, from the front and from the side; otherwise you would not give true knowledge of their ramifications, shape and position.

The ventricles of the brain and the ventricles of the semen are equally distant from the ventricles of the heart.

Quaderni V 2 r.

[*Muscles represented by strings of fire-heated copper wire*]

Make this leg in full relief, and make the tendons of copper wire that has been heated in the fire; and then bend these according to their natural form; and having done this you will be able to draw them from four sides, and to place them as they are in nature and to speak about their functions.

The immediate causes of the movements of the legs are entirely separated from the immediate cause of the movement of the thigh, and this is what makes the power.

[*Of the muscles*]

When you have finished the bones of the legs put the number of all the bones, and at the end of the tendons set down the number of these

LEFT LEG IN THREE POSITIONS TO SHOW BONES AND TENDONS

Royal Library, Windsor

[Text: I. 188-9]

tendons. And you should do the same with the muscles, the sinews, the veins and arteries, saying:—the thigh has so many, and the leg so many and the feet so many and the toes so many; and then you should say:—so many are the muscles which start from the bones and end in the bones, and so many are those which start from the bones and end in another muscle; and in this way you describe every detail of each limb, and especially as regards the ramifications made by certain muscles in producing different tendons.

These four legs should be on one and the same sheet of paper so that you may be the better able to understand the positions of the muscles and to recognise them from different sides.

Quaderni v 4 r.

[*Anatomy of the brain with details of an experiment to discover the true form of the ventricles*]

After we have clearly seen that the ventricle *a* is at the end of the neck where pass all the nerves which communicate the sense of touch we may judge that this sense of touch passes into such ventricle, seeing that nature works in all things in the briefest time and way possible; therefore the sense would go with longer time.

[*Experiment*]

Make two air holes in the horns of the great ventricles and insert melted wax by means of a syringe, making a hole in the ventricle of the memoria, and through this hole fill the three ventricles of the brain; and afterwards when the wax has set take away the brain and you will see the shape of the three ventricles exactly. But first insert thin tubes in the airholes in order that the air which is in these ventricles may escape and so make room for the wax which enters into the ventricles.[1]

Drawing with names of parts:—imprensiva, sensus communis, memoria.

Model of the sensus communis.

Cast in wax at the bottom of the base of the cranium through the hole *m* before the cranium was sawn through.

Quaderni v 7 r.

[*Anatomy of intestines*]

Draw the intestines in their position and detach them ell by ell, first tying up the ends of the part removed and the part remaining.

[1] According to the editors of the Quaderni, Leonardo was the first to make casts of the cerebral ventricles, and several hundred years elapsed before the idea occurred to any other anatomist.

And after you have removed them you must draw the margins of the mesentery from which you detach such part of the intestine; and when you have drawn the position of this intestine you will draw the ramification of its vessels; and so you will go on in succession until the end.

And you will commence on the right intestine but you will make the entry on the left side at the colon. But first of all you must remove with your chisel the pubic bone and the bones of the hips in order to observe accurately the position of the intestines.

Quaderni v 24 r.

Nature has made all the muscles which connect with the movements of the toes attached to the bone of the leg and not to the thigh, for if they were attached to the bone of the thigh, they would fold up when the knee-joint was bent and become fixed under the knee-joint, and not be able without great difficulty and fatigue to serve these toes; and the same happens with the hand, by means of the bending of the elbow of the arm.

Quaderni VI 17 r.

Uncover gradually all the parts on the front side of a man when you make your anatomy; and so continue to do even to the bones.

Quaderni VI 21 r.

CONCERNING THE HUMAN FORM

Which part is that in man which never puts on flesh as he grows fat?

Which is that part which as a man becomes thin is never reduced with too perceptible a thinness?

Among the parts which grow fat which is that which grows most fat?

Among the parts which become emaciated which is that which becomes most emaciated?

Among men who are powerful in strength which muscles are of greater thickness and more prominent?

You have to represent in your anatomy all the stages of the limbs from the creation of man down to his death, and down to the death of the bones, and (to show) which part of these is first consumed and which part is preserved longer.

And similarly from the extreme of leanness to the extreme of fatness.

ON PAINTING

Which muscles are those which stand out as people grow old or in the young when they become lean?

Which are the places in the human limbs in which the flesh never increases on account of any degree of fatness or diminishes on account of any degree of leanness.

What has to be sought for in this question will be found in all the surface joints of the bones, as shoulder, elbow, joints of the hands and fingers, hips, knees, ankles and toes and similar things which shall be spoken of in their places.

The greatest thickness which the limbs acquire is in the part of the muscle that is farthest away from their attachments.

The flesh never increases upon the parts of the bones which are near the surface of the limbs.

In the movement of man, nature has placed all those parts in front which on being struck cause a man to feel pain; so it is felt in the shins of the legs and in the forehead and nose. And this is ordained for man's preservation, for if such power of enduring suffering were not inherent in these limbs the numerous blows received on them would be the cause of their destruction.

Quaderni VI 22 r.

OF THE MOVEMENTS OF THE FINGERS OF THE HANDS

The movements of the fingers are chiefly those of extension and bending. Extension and bending are done in various ways, that is sometimes by bending all in one piece at the first joint, at another time by bending or straightening themselves half way at the second joint, and at another time by bending in their whole length and at the same time in all the three joints. If the two first joints are prevented from bending the third joint will bend more readily than before, but it can never bend of itself alone if the other joints are free, but all the three joints must bend. In addition to the above-mentioned movements there are four other chief movements, of which two are upwards and downwards, and the two others go from side to side, and each of these is produced by a single tendon. From these there follow an infinite number of other movements made always with two tendons; and if one of these tendons does not function properly the other takes its place. The tendons are

made thick on the inside of the finger and thin on the outside; and on the inside they are attached to every joint but not on the outside.

C.A. 99 v. a

OF THE MUSCLES

Nature has provided man with functional muscles which draw the sinews and these are able to move the limbs according to the will and desire of the common sense, after the manner of officials stationed by their lord through various provinces and cities to represent and carry out his will in these places. And the official who on more than one occasion has carried out the commission given him by the mouth of his lord will then himself at the same time do something which does not proceed from the will of the lord. So one often sees with the fingers how after having with utmost docility learnt things upon an instrument as they are commanded by the judgment they will afterwards play them without the judgment accompanying. The muscles which move the legs do not however perform their functions without the man becoming conscious of it.

C.A. 119 v. a

Saw a head in two between the eyebrows in order to find out by anatomy the cause of the equal movement of the eyes, and this practically confirms that the cause is the intersection of the optic nerves, that is of the equality of movement, if the eyes observe minutely the parts of a circle, and there are nerves which cause them to make a circular movement.

C.A. 305 v. b

OF ARTERIES

There are three varieties of arteries, of which one is wide at the bottom and narrow at the mouth, another wide at the mouth and narrow at the bottom, and the third is of uniform width.

C.A. 369 v. e

The navel is the point of junction of the offspring with the sheath which clothes it; it spreads out branches and is attached to the matrix as a button is to a buttonhole, a briar to a briar or a burr to a burr.

C.A. 385 r. a

OF THE NERVES

The hand that holds the stone within it when it is struck with a

hammer feels a part of the pain which the stone would feel if it were a sentient body.

A 33 r.

OF THE BLOOD THAT THERE IS IN THE CROWN OF THE HEAD

It would seem to be a simple proposition that if anyone should break the crown of a man's head nothing would flow forth from this fracture except such blood as lay between its edges. In fact every heavy thing seeks low places; blood possesses weight and it appears impossible that of itself it could ever rise to a height like an aerial and light thing. And if you wished to say that by the extension that the lung makes in the lake of blood, when this lung in the ingathering of the breath fills itself with air, and in becoming deflated drives from the lake the blood, which escapes into the veins and makes them increase and swell, and that it is this swelling which causes this blood to flow out from the above named fracture of the crown of the head, this opinion is at once confuted by the fact that the veins are quite capable and adapted to serve as a convenient receptacle for the increase of the blood without it having to flow out by the fracture of the head as though deprived of such receptacle.

WHY THIS BLOOD ESCAPES BY THE CROWN OF THE HEAD

The spiritual parts have power to move and to carry with them in their course the material parts. We see that fire by reason of its spiritual heat sends out of the chimney amid the steam and smoke matter that has body and weight, as is seen with soot which if you burn you will see reduced to ashes. So the heat that is mingled with the blood finding itself evaporate by the fracture of the head desiring to return to its element, carries in its company the blood with which this heat is infused and intermingled. The reason why the smoke rises up with such fury and carries substances with it is that as the fire attaches itself to the wood it is nourished and fed by a fine moisture, and as this moisture becomes thicker than can be consumed by the heat that is within the fire, the fire desires to return to its element, and carries the heated vapours with it, as may be seen if you distil quicksilver in a retort; you will see that when this silver of so great weight is mingled with the heat of the fire it

ascends and then in smoke falls down again into the second container and retakes its former nature.

A 56 v. and 57 r.

Observe how the shoulder changes with all the movements of the arm, moving up and down, inwards and outwards, backwards and forwards, and so also with turning movements or any other movements. And do the same with the neck the hands and feet and the chest above the hips.

E 17 r.

PAINTING

O painter skilled in anatomy, beware lest the undue prominence of the bones sinews and muscles cause you to become a wooden painter from the desire to make your nude figures reveal all their emotions. And if you wish to remedy this you should consider in what way the muscles of old or lean persons cover or clothe the bones, and furthermore note the principle on which these same muscles fill up the spaces of the surface which come between them, and which are the muscles that never lose their prominence in any degree of fatness whatsoever, and which those whereof the tendons become indistinguishable at the least suggestion of it. And there are many cases when several muscles grow to look one from the increase of fat, and many in which when any one becomes lean or old a single muscle divides into several; and in this treatise all their peculiarities shall be set forth each in its place, and especially with regard to the spaces that come between the joints of each limb. Further you should not fail to observe the variations of the aforesaid muscles round the joints of the limbs of any animal, due to the diversity of the movements of each limb; for on no side of these joints does the indication of these muscles become completely lost by reason either of the increase or diminution of the flesh of which these muscles are composed.

And you should do the same for a child from its birth down to the time of its decrepitude, through all the stages of its life, such as infancy, childhood, adolescence, youth etc. And in all you should describe the changes of the limbs and joints and show which grows fat and which thin.

E 19 v. and 20 r.

Describe which are the muscles and tendons that become prominent or concealed through the different movements of each limb, and which

do not do either. And remember that such action is very important and very necessary for such painters and sculptors as profess to be masters.

E 20 r.

Which nerves or sinews of the hand [or foot] are those that bring close together and separate from each other the fingers and toes of the hands and the feet?

F 95 v.

The heart is a principal muscle in respect of force, and it is much more powerful than the other muscles.

I have written of the position of the muscles which descend from the base to the point of the heart, and the position of the muscles which spring from the point of the heart and go to the summit.

The auricles of the heart are the ante-chambers of this heart which receive the blood from the heart when it escapes from its ventricle from the beginning to the end of the pressure, for unless a part of this quantity of blood escaped the heart would not be able to shut.

G I v.

Give the anatomy of the leg up to the hip from all its sides, in every action, so as to show everything; veins, arteries, nerves, tendons and muscles, skin and bones; then with the bones in section in order to show the thickness of the bones.

K 108 [28] r.

[*Sinews and muscles*]

The sinew which guides the leg which is joined to the kneecap feels it more effort to raise the man up in proportion as the leg is more bent. The muscle which acts upon the angle formed by the thigh at its junction with the bust has less difficulty and has less weight to raise because it does not have the weight of the thigh; and besides this it has stronger muscles because they are those which form the buttocks.

L 27 v.

Piscin da Mozania at the hospital of Brolio has many veins.
For the arms and legs.

Forster II 65 r.

The simple members are eleven, namely cartilage, bones, nerves, veins, arteries, membranes, ligaments and tendons, skin and flesh and fat.

OF THE HEAD

The parts of the vessel of the head are ten, namely five external and five internal.

The external are:— hair and skin, muscular flesh, large membrane and the skull. The internal are these:— dura mater, pia mater, brain; below return the pia mater and the dura mater which enclose the brain between them, then there is the rete mirabile, and then the bone foundation of the brain, and from thence proceed the nerves.

Forster III 27 v.

[*Drawing — head in median section*]

a hair, *n* skin, *c* muscular flesh, *m* large membrane, *o* skull, that is bone of skull.

b dura mater, *d* pia mater, *f* brain.

r pia mater below, *t* dura mater, *l* rete mirabile, *s* bone foundation.

Forster III 28 r.

Hippocrates says that the origin of our semen is derived from the brain, and from the lungs and testicles of our forefathers where the final decoction is made; and all the other members transmit their substance to this semen by sudation, because there are no apparent channels by which they could arrive at this semen.

Forster III 75 r.

IV

Comparative Anatomy

'Second demonstration interposed between the anatomy and the life.

For this comparison you should represent the legs of frogs, for these have a great resemblance to the legs of the man both in the bones and in the muscles.'

[*Comparative Anatomy*]

Represent here the foot of the bear and of the monkey and of other animals as far as they differ from the foot of man; and put also the feet of certain of the birds.

Fogli A 17 r.

[*Comparative Anatomy*]

[*Drawing of arm*] Man *a b m n*.

[*same*] Monkey *c d p o*.

In proportion as the nerve *c d* takes the bone *o p* nearer to the hand so this hand raises a greater weight; and this is the case with the monkey which is more powerful in its arms than the man is according to his proportion.

Fogli B 9 v.

[*Man, Lion, Horse, Bull*]

Man. The description of man, in which is contained those who are almost of the same species just as the baboon, the ape and others like these which are many.

Lion and its followers, such as panthers, lions, tigers, leopards, lynxes, Spanish cats, *gannetti* and ordinary cats and the like.

Horse and its followers such as the mule, the ass and the like which have teeth above and below.

Bull and its followers which are horned and without upper teeth, such as buffalo, stag, fallow-deer, roebuck, sheep, goats, ibex, milch cows, chamois, giraffes.

Fogli B 13 r.

[*Organs of the senses in man as compared with those of other animals*]

I have found in the constitution of the human body that as among all the constitutions of the animals it is of more obtuse and blunt sensibilities, so it is formed of an instrument less ingenious and of parts less capable of receiving the power of the senses. I have seen in the leonine species how the sense of smell forming part of the substance of the brain it descends in a very large receptacle to meet the sense of smell which enters among a great number of cartilaginous cells with many passages that go to meet the above-mentioned brain.

The eyes of the leonine species have a great part of their head as their receptacle, so that the optic nerves may be in immediate conjunction

with the brain. With man the contrary is seen to be the case for the cavities of the eyes occupy but a small part of the head, and the optic nerves are thin and long and weak; consequently as one sees they work feebly by day and worse by night, whereas the aforesaid animals see better by night than by day; and the sign of this is seen in the fact that they hunt their prey by night and sleep by day as do also the nocturnal birds.

The light or pupil of the human eye as it expands or contracts gains or loses the half of its size; and in the nocturnal animals its increase or decrease is more than a hundred times. This may be seen in the eye of the owl a nocturnal bird by bringing a lighted torch near to it, and still more by making it look at the sun, for then you will see the pupil which once occupied the whole of the eye diminished to the size of a grain of millet, and by this diminution it becomes equal to the pupil of the eye of man and clear shining things seem the same colour to it as they appear at this time to man, and as much more as the brain of this creature is less than the man's brain: from which it comes about that as the pupil increases in the night time a hundred fold more than that of the man it sees a hundred times as much light as the man does, in such a way that this power of sight is not afterwards subdued by the darkness of night. And the pupil of man which only doubles its quantity sees only faint light and almost like the bat which does not fly in times of too great darkness.

Fogli B 13 v.

[*Differences between the human intestines and those of other animals*]

Write of the varieties of the intestines of the human species, apes and such like; then of the differences that are found in the leonine species, then the bovine and lastly in birds; and make this description in the form of a discourse.

Fogli B 37 r.

Then you shall make a discourse on the hands of each animal in order to show how they vary, as in the bear in which the ligaments of the tendons of the toes of the foot are connected over the neck of the foot.

Quaderni I 2 r.

Describe the tongue of the woodpecker and the jaw of the crocodile.

Quaderni I 13 v.

Take out a bull's liver to make an anatomy.

Quaderni II 6 v.

ONION AND HUMAN HEAD IN SECTION

Royal Library, Windsor

[Text : I. 201]

Look at the dead dog, its lumbar muscles and diaphragm and the movement of its ribs.

Quaderni II 7 v.

Analyse the movement of the tongue of the woodpecker.

Quaderni IV 10 r.

[*With drawings of onion and human head in section*]

If you cut an onion down the centre you will be able to see and count all the coatings or rinds which form concentric circles round the centre of this onion.

Similarly if you cut a man's head down the centre you will cut through the hair first, then the skin and the muscular flesh and the pericranium, then the cranium and within the dura mater and the pia mater and the brain, then the pia and dura mater again and the rete mirabile and the bone which is the foundation of these.

Quaderni V 6 v.

[*With figures*]

[*Comparative anatomy. Bones and joints. Muscular contours in obesity and in emaciation*]

Junction of the fleshy muscles with the bones, without any tendon or cartilage — and you should do the same for several animals and birds.

Show a man on tiptoe so that you may compare a man better with other animals.

Represent the knee of a man bent like that of the horse.

To compare the bone structure of the horse with that of the man you should show the man on tiptoe in representing the legs.

Of the relationship that exists between the arrangement of the bones and muscles of the animals and that of the bones and muscles of the man.

Show first the bones separated with the sockets where they join, and then join them together, and especially the hip-joint or the joint of the thigh.

Describe which muscles disappear in the process of growing fat, and which are uncovered as one becomes emaciated.

And note that those portions of the surface of the fat which protrude most will stand out most when one grows thin.

Where the muscles are separated from one another you should show outlines, and where they are tightly fastened together; and you should draw only with the pen.

Quaderni V 22 r.

SECOND DEMONSTRATION INTERPOSED BETWEEN THE ANATOMY AND THE LIFE[1]

For this comparison you should represent the legs of frogs, for these have a great resemblance to the legs of the man, both in the bones and in the muscles; you should afterwards follow this with the hind legs of the hare, for these are very muscular and the muscles are well defined because they are not hampered by fat.

Quaderni v 23 r.

[*Diagrams*]

PUPIL OF OWL. PUPIL OF MAN

The pupil *c* represents its size in the daytime, that is at the greatest brightness of the day.

a c shows how it increases in the maximum darkness of the night, and so it goes changing from a greater to a less quantity according to the greater or less obscurity of the night.

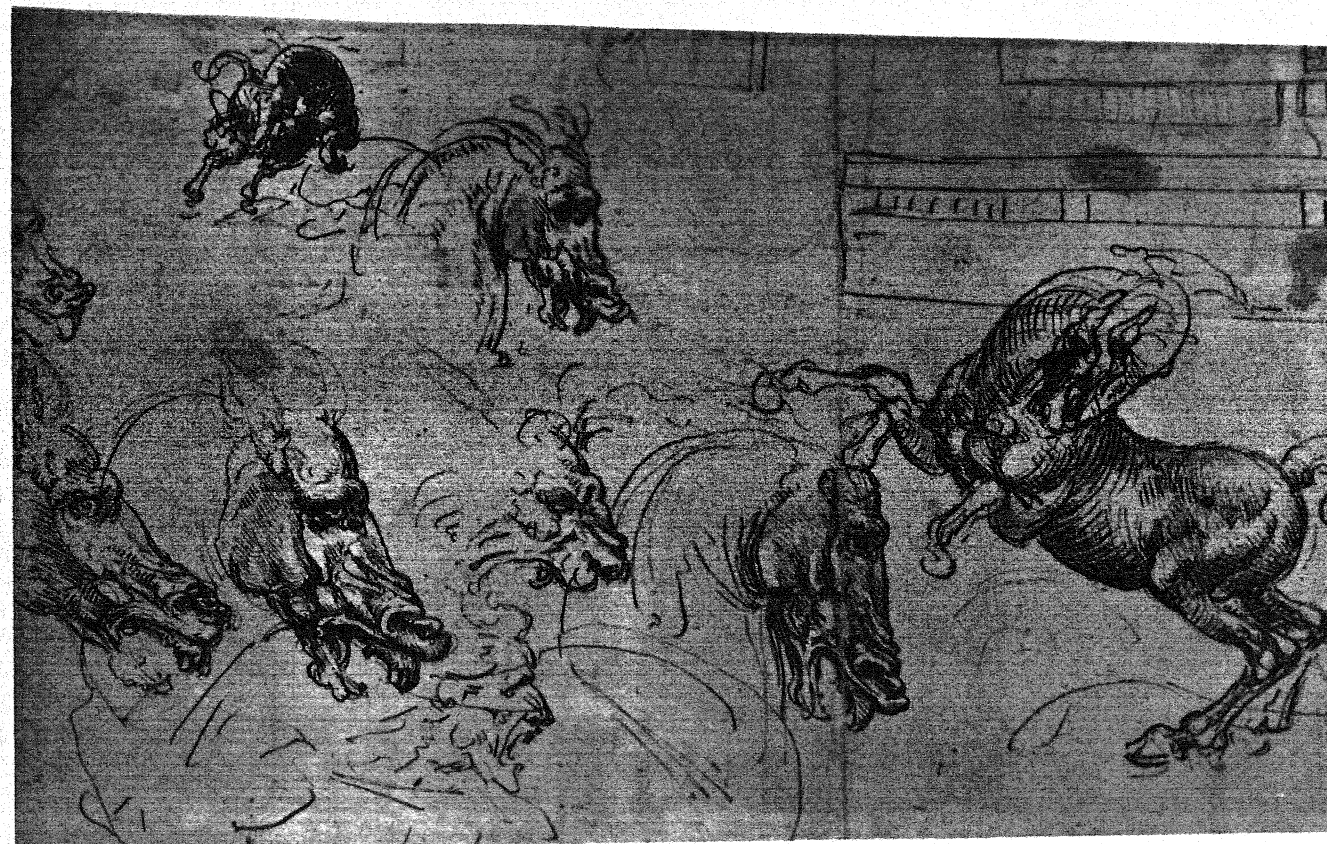
PUPIL OF CAT

If the darkness of night is a hundred degrees more intense than that of evening, and the eye of man doubles the size of its pupil in darkness, this darkness is lessened by half in this eye because it has redoubled half its visible potency: there remain therefore fifty degrees of intensity of darkness. And if the eye of the owl has its pupil increased a hundred times in the aforesaid darkness it increases its visual capacity one hundred times, so that one hundred degrees of visual capacity are acquired, and because things which are equal do not overcome one another the bird sees in the darkness with the pupil increased a hundredfold as in the day with the pupil diminished ninety nine parts in the hundred.

And if you were to say that this animal does not see light by day and for this reason it remains shut up, to this I reply that the bird only shuts itself up in the day in order to free itself from the mobbing of birds which in a great multitude always surround it with a loud clamour, and frequently they would be put to death if they did not hide themselves in the grottos and caverns of the high rocks.

Of the nocturnal animals only the lion species changes the shape of its pupil as that enlarges or lessens: for when it is at the utmost stage of

[1] This passage is cited by the editors of the Quaderni d'Anatomia as a proof of Leonardo having acquired a full understanding of the difference between scientific anatomical dissection and contour anatomy.



HEADS OF HORSES, LION AND MAN, AND HORSE GALLOPING

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diminution it is long in shape, when half way it is oval, and when it has attained to its utmost expansion it is circular in shape. C.A. 262 r. d

[*With sketches of head of horse*]

The distance between the one ear (of a horse) and the other should equal the length of one of the ears.

The length of the ear should be the fourth part of the face.

A 62 v.

Death in the old without fever is caused by the skin of the veins which go from the spleen to the gate of the liver becoming so thick that they close up and no longer allow a passage to the blood which feeds them.

The continual passing of the blood in these veins makes them thicken and harden so that at last they close up and prevent the passage of the blood.

The spaces or hollows in the veins of the animals and the long course of the humour that nourishes them harden and finally contract. The hollows of the veins of the earth come to be enlarged through the long continuous passage of the water. F I r.

MUSCLES OF ANIMALS

The hollows interposed between the muscles should not be of such a kind that the skin seems as though it covers two sticks placed to touch each other, as in *c*; and not in such a way as to seem like two sticks at a little distance from each other and with the skin hanging idly with a loose curve as in *f*; but it should be as in *i*, laid over the spongy fat that lies between the angles, as in the angle *n m o*, which angle springs at the end of the contact of the muscles. And because the skin cannot descend into such an angle nature has filled it with a small quantity of spongy or as I prefer to call it vesicular fat, that is containing small cells full of air, which become condensed or rarefied according to the increase or rarefaction of the substance of the muscles; in which case the hollow *i* has always a greater curve than the muscle. G 26 r.

Make an anatomy of different eyes and see which are the muscles that open and close the above mentioned pupils of the eyes of animals.

OF THE EYES OF ANIMALS

The eyes of all animals have pupils which have power to increase or diminish of their own accord according to the greater or less light of the sun or other luminary. In birds however the difference is greater, and especially with nocturnal birds of the owl species such as the long-eared the white and the brown owls; for with these the pupil increases until it almost covers the whole eye or diminishes to the size of a grain of millet, preserving all the time its round shape. But in the lion species such as panthers, leopards, lionesses, tigers, wolves, lynxes, Spanish cats and others the pupil as it diminishes changes from the perfect circle to an elliptical figure thus [*fig.*] as is seen in the margin. Man however having a more feeble vision than any other animal is less hurt by excessive light and his pupil undergoes less increase in dark places. As regards the eyes of the above-mentioned nocturnal animals, in the horned owl which is the largest nocturnal bird the power of vision is so much increased that even in the faintest glimmer of night which we call darkness it can see more distinctly than we in the radiance of noon, when these birds stay hidden in dark recesses; or if they are compelled to emerge into the sunlit air the pupil contracts so much that the power of vision diminishes at the same time as the size of the pupil.

G 44 r.

[*Drawings of part of skeleton of horse*]

Of the muscles that attach themselves to the bone. Horse.

K 102 [22] r.

[*Drawing: part of skeleton of horse*]

Here I make a note to show the difference there is between man and horse and in the same way with the other animals.

I commence first with the bones, and then go on to all the muscles which proceed from and end in the bones without tendons, then to those which proceed from and end in the bones with tendons and then those which have a single tendon on one side.

K 109 [29-30] v.

When the eye of the bird closes with its two coverings it closes first the secondina, and this closes it from the lachrymal gland as far as the angle of the eye, and the first (covering) closes it from below upwards. And these two movements having intersected cover it first from the direction of the lachrymal gland, because they have already seen themselves safeguarded in front and below; and they only reserve the

STUDIES OF HORSES AND RIDERS FIGHTING DRAGONS

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upper part because of the dangers from birds of prey which descend from above and behind, and they will first uncover the membrane in the direction of the angle, for if the enemy comes behind the bird will have the opportunity of flying forward. It also has the membrane called the secondina of such texture as to be transparent, for if it did not possess this shield it would not be able to keep its eyes open against the wind which strikes the eye in the fury of its swift flight. And its pupil expands and contracts as it beholds less or greater light, that is, radiance.

B.M. 64 V.

[*Sketch — bust of man and measurements*]

The trunk *a b* will be one foot at its narrowest part, and from *a* [to] *b* will be two feet which will form two squares.

And the horse in its narrowest part goes three times into the length which makes three squares.

Quaderni VI 4 r.

V

Physiology

'The frog instantly dies when the spinal cord is pierced; and previous to this it lived without head without heart or any bowels or intestines or skin; and here therefore it would seem lies the foundation of movement and life.'

[*Experimental investigations of spinal cord and intestines of frog*]
[*with drawing*]

Sense of touch
cause of movement
origin of the nerves
transit of the animal powers

REPRODUCTIVE POWER

The frog retains life for some hours when the head the heart and all the intestines have been taken away. And if you prick the said cord it instantly twitches and dies.

All the nerves of the animals derive from here: when this is pricked it instantly dies.

Quaderni v 21 r.

[*Experimental investigation of the spinal cord of frog*]

The frog instantly dies when the spinal cord is pierced; and previous to this it lived without head without heart or any bowels or intestines or skin; and here therefore it would seem lies the foundation of movement and life.

Hand of monkey [*drawing*]

[*Drawing*] In this manner originate the nerves of movement above . . . knot of the spine.

[*Drawing*] Whichever of these is pricked is lost in the frog.

Quaderni v 21 v.

Where there is life there is heat; where there is vital heat there is movement of the watery humours.

C.A. 80 r. b

The common sense is that which judges the things given to it by the other senses.

[*The common sense is set in motion by the things given to it by the five senses*]

And these senses are moved by the objects, and these objects send their images to the five senses by which they are transferred to the organ of perception (imprensiva) and from this to the common sense; and from thence being judged they are transmitted to the memory, in which according to their potency they are retained more or less distinctly.

[*The five senses are these: seeing, hearing, touch, taste, smell*]

The ancient speculators have concluded that that faculty of judgment which is given to man is caused by an instrument with which the other five are connected by means of the organ of perception (imprensiva), and to this instrument they have applied the name common sense, and they say that this sense is in the centre. And this name common sense they use simply because it is the common judge of the other five senses, namely seeing, hearing, touch, taste and smell. The common sense is set in movement by means of the organ of perception (imprensiva) which is situated in the centre between it and the senses. The organ of perception acts by means of the images of the things presented to it by the superficial instruments, that is the senses, which are placed in the middle between the external things and the organ of perception; and the senses act in the same way through the medium of objects.

The images of the surrounding things are transmitted to the senses, and the senses transmit them to the organ of perception, and the organ of perception transmits them to the common sense, and by it they are imprinted on the memory, and are retained there more or less distinctly according to the importance or power of the thing given. That sense functions most swiftly which is nearest to the organ of perception; this is the eye, the chief and leader of the others; of this only we will treat and leave the others in order not to lengthen out our material.

Experience tells us that the eye has cognisance of ten different qualities of objects; to wit, light and darkness — one serving to reveal the other nine, the other to conceal them — colour and substance, form and position, distance and nearness, movement and rest.

C.A. 90 r. b

OF THE GROWTH OF MAN

A man at three years will have reached the half of his height.

A woman of the same size as a man will weigh less than he does.

A dead woman lies face downwards in water, a man the opposite way.

C.A. 119 v. a

How radiating lines carry visual potency with them as far as the striking point:

This our mind or common sense which the philosophers affirm makes its dwelling in the centre of the head keeps its spiritual members at a great distance away from itself, and this is clearly seen in the lines

of the visual rays which after terminating in an object transmit immediately to their cause the characteristics of the form of their breaking.

Also — in the sense of touch which derives from the common sense — does not one see it extending itself with its power as far as the tips of the fingers, for as soon as these points have touched the object the sense is immediately made aware of whether it is hot or cold or hard or soft or pointed or smooth.

C.A. 270 v. b

OF THE GAIT OF MAN

The gait of man is always after the manner of the universal gait of four-footed animals; seeing that as these move their feet crosswise, as a horse does when it trots, so a man moves his four limbs crosswise, that is if he thrusts the right foot forward as he walks he thrusts the left arm forward with it, and so it always continues.

C.A. 297 r. b

Men born in hot countries love the night because it makes them cool, and they hate the sunlight because it causes them to grow hot again; and for this reason they are of the colour of the night, that is black; and in the cold countries everything is the opposite.

C.A. 393 v. a

That cause which moves the water through its springs against the natural course of its gravity is like that which moves the humours in all the shapes of animated bodies.

C.A. 396 r. a

The potencies are four: memory and intellect appetite and concupiscence.

The two first are of the reason the others of the senses.

Of the five senses, seeing, hearing, smelling may be partially withheld — touch and taste, not.

The sense of smell leads that of taste with it, in the dog and other greedy animals.

Tr. 12 a

All the spiritual powers, in proportion as they are farther away from their primary or secondary cause, occupy more space and become of less potency.

Tr. 18 a

As to the bendings of the joints and in what manner the flesh grows on them in their folds and extensions. Of this most important study

make a separate treatise in the 'Description of the movements of animals with four feet', among which is man who also in infancy goes on four feet.
E 16 r.

When a man is walking he carries his head in advance of his feet.

When a man in walking traverses a level expanse he bends forward at first and then bends as far backward.
F 83 r.

It is impossible to breathe through the nose and through the mouth at the same time. The proof of this is seen when anyone breathes with the mouth open taking the air in through the mouth and giving it out through the nose, for then one always hears the sound of the gate set near to the uvula when it opens and shuts.
G 96 v.

Dead bodies when male float in water on their backs, when female face downwards.
H 31 v.

If when going up a staircase you rest your hands upon your knees all the strain which comes upon the arms is so much taken away from the tendons below the knees.
H 75 [27] r.

We make our life by the death of others.

In dead matter there remains insensate life, which, on being united to the stomachs of living things, resumes a life of the senses and the intellect.
H 89 [41] v.

Every body is composed of those members and humours which are necessary for its support; which necessity is well known and provided for it by the soul, which has chosen such shape of body for a time as its habitation.

Consider the fish, which on account of the continuous friction that of necessity it makes with the water, from its own life being a daughter of nature, it is prepared to be delivered, by reason of the porosity that is found to exist between the joints of the scales, of a certain slimy discharge, which with difficulty becomes separated from this fish and performs that function towards the fish that pitch does to the ship.
Forster III 38 r.

If you draw in breath by the nose and send it out by the mouth you will hear the sound made by the partition, that is the membrane in . . .
Fogli A 3 r.

VI

Natural History

'Why is the fish in the water swifter than the bird in the air when it ought to be the contrary, seeing that the water is heavier and thicker than the air, and the fish is heavier and has smaller wings than the bird?'

Lobsters and crabs are empty at the waning of the moon, for there is little light for them to feed themselves by, and if one brings them a light at night they all hasten to this light.

And when the moon is at the full they see their food well and eat of it abundantly.

C.A. 165 v. b

Why is the fish in the water swifter than the bird in the air when it ought to be the contrary seeing that the water is heavier and thicker than the air and the fish is heavier and has smaller wings than the bird? For this reason the fish is not moved from its place by the swift currents of the water as is the bird by the fury of the winds amid the air; and in addition to this we may see the fish speeding upwards on the very course down which water has fallen abruptly with very rapid movement, after the manner of lightning amid the incessant clouds, which seems a marvellous thing. And this results from the immense speed with which it moves which so exceeds the movement of the water as to cause it to seem motionless in comparison with the movement of the fish. The proportion of the said movements is as one is to ten; the movement of the water being as one and that of the fish ten and exceeding it therefore by nine. Therefore although the fish has the power ten it is left with the power nine, for as it leaps up the descent — its power being ten and the water taking away one from it — nine remains.

This happens because the water is of itself thicker than the air and in consequence heavier, and therefore it is swifter in filling up the vacuum which the fish leaves behind it in the place from whence it departs, and also the water which it strikes in front of itself is not compressed as is the air in front of the bird but rather makes a wave which by its movement prepares the way for and increases the movement of the fish, and for this reason it is swifter than the bird in front of which the air is condensed.

C.A. 168 v. b

HOW OXEN FEED ON TALL PLANTS

Oxen in order to feed on the leaves of tall slender plants such as young poplars and the like are in the habit of raising themselves up, so that they stride with their legs across the base of the plant and press continually forward in such a way that the plant, being unable to bear

up against the oppressive weight, is obliged to give way and bow down its lofty top.

C.A. 297 r. b

[*With drawing of moth*]

The *pannicola* flies with four wings, and when those in front are raised those behind are lowered.

But it is necessary for each pair to be of itself sufficient to sustain the whole weight.

When the one is raised the other is lowered.

In order to see the flying with four wings go into the moats and you will see the black *pannicole*.

C.A. 377 v. b

VII

Human Proportions

'The span of a man's outstretched arms is equal
to his height.'

[*Proportions of the human figure*]

From the chin to the starting of the hair is a tenth part of the figure.

From the junction of the palm of the hand as far as the tip of the middle finger a tenth part.

From the chin to the top of the head an eighth part.

And from the pit of the stomach to the top of the chest is a sixth part.

And from the fork of the ribs as far as the top of the head a fourth part.

And from the chin to the nostrils is a third part of the face.

And the same from the nostrils to the eyebrows, and from the eyebrows to the starting of the hair.

And the foot is a sixth part, and the forearm to the elbow a fourth part. The breadth across the shoulders a fourth part. C.A. 358 r. a

There is as great a distance between the commencement of the one ear and that of the other as there is from the space between the eyebrows to the chin.

The size of the mouth in a well proportioned face is equal to the distance between the parting of the lips and the bottom of the chin.

A 62 v.

[*With sketches of heads*]

The cut or angle of the lower lip is midway between the bottom of the nose and the bottom of the chin.

The face in itself forms a square, of which the breadth is from one extremity of the eyes to the other, and the height is from the top of the nose to the bottom of the lower lip, and what is left over above and below this square has the height of a similar square.

The ear is precisely as long as the nose.

The slit of the mouth when seen in profile points to the angle of the jaw.

The length of the ear should equal the distance from the bottom of the nose to the top of the eyelid.

The space between the eyes is equal to the size of one eye.

In profile the ear is above the middle of the neck. A 63 r.

[*Proportions*]

The foot from the toe to the heel goes twice into the space from the heel to the knee, that is to say where the bone of the leg is joined to that of the thigh.

The hand as far as where it unites with the bone of the arm goes four times into the space from the tip of the longest finger to the joint of the shoulder.

B 3 V.

Every man at the third year is half his height.

H 31 V.

[*Weight and movements of man*]

The leg as far as its junction with the thigh is a quarter of the whole weight of the man.

The man draws more weight downwards than upwards, first because he gives more of his weight out of his central line, then because he passes all his foot from the central line; and thirdly because he does not slip with his feet.

L 28 r.

The space between the line of the mouth and the beginning of the nose *a b*, is the seventh part of the face.

The space from the mouth to the bottom of the chin *c d*, is the fourth part of the face and equal to the width of the mouth.

The space from the chin to the beginning of the bottom of the nose *e f*, is the third part of the face and equal to the nose and to the forehead.

The space from the middle of the nose to the bottom of the chin *g h* is half the face.

The space from the beginning of the top of the nose where the eyebrows begin, *i k*, to the bottom of the chin is two thirds the face.

The space between the line of the mouth and the beginning of the chin above, *l m*, that is where this chin ends terminating with the under lip, is the third part of the distance from the line of the mouth to the bottom of the chin and the twelfth part of the face; from the top to the bottom of the chin *m n* is the sixth part of the face, and it is the fifty-fourth part of the man.

From the point of the chin to the throat *o p*, is equal to the space from the mouth to the bottom of the chin and the fourth part of the face.

The space from the top of the throat to its beginning below, *q r*, is half the face and the eighteenth part of the man.

From the chin to the back of the neck *s t* is the same distance as is between the mouth and the beginning of the hair, that is three quarters of the head.

From the chin to the jaw *v x* is half the head and equal to the thickness of the neck in profile.

The thickness of the neck goes one and three quarter times from the eyebrow to the nape of the neck.

Quaderni VI 4 r.

The whole foot will go between the elbow and the wrist, and between the elbow and the inner angle of the arm towards the breast when the arm is folded. The foot is as long as the whole head of the man, that is from beneath the chin to the very top of the head as is here shown.

The foot goes three times from the tip of the long finger to the shoulder, that is to its joint.

The nose will make two squares; that is the breadth of the nose at the nostrils will be contained twice between the point of the nose and the beginning of the eyebrows; and similarly in profile the distance from the extreme edge of the nostril, where it unites with the cheek, to the tip of the nose, will be equal to the width of the nose in front from one nostril to the other.

If you divide into four equal parts the whole length of the nose, that is from its tip to the insertion of the eyebrows, you will find that one of these parts extends from the top of the nostrils to the bottom of the point of the nose, and the upper part extends from the lachrymatory duct of the eye to the insertion of the eyebrows; and the two parts in the middle are equal to the length of the eye from the lachrymatory duct to its corner.

Quaderni V 5 r.

From the roots of the hair to the top of the breast *a b* is a sixth of a man's height; and this measure never varies.

It is as far from the outside part of one shoulder to another as it is from the top of the breast to the navel, and this goes four times into the distance from the sole of the foot to where the bottom of the nose begins.

The arm, from where it separates itself from the shoulder in front, goes six times into the space between the two extremities of the shoulders

and three times into a man's head and four into the length of the foot and three into the hand whether on the inside or the outside.

Quaderni VI 6 r.

The foot from its beginning in the leg as far as the extremity of the big toe is equal to the space between the beginning of the top of the chin and the starting of the hair *a b*, and it is equal to five sixths of the face.

Quaderni VI 7 v.

If anyone kneels down he will lessen his height by a fourth part.

If a man be kneeling with his hands across his breast the navel will be at the half of his height and so will be the points of the elbows.

The half of a man seated, that is from the seat to the crown of the head, will be from the arm below the breast and below the shoulder; this seated portion, that is from the seat to the crown of the head, will exceed the half the man's height by the breadth and length of the testicles.

Quaderni VI 8 r.

A cubit is the fourth part of a man's height and it is equal to the greatest width of the shoulders. From the one shoulder joint to the other is twice the head, and it is equal to the distance from the top of the breast to the navel. From this top to the commencement of the penis is the length of a head.

Quaderni VI 8 v.

The foot is as much longer than the hand as the thickness of the arm to the wrist, that is where it is thinnest, seen in front.

Also you will find that the foot is as much longer than the hand as the space on the inner side from the join of the little toe to the last projection of the big toe, taking the measure along the length of the foot.

The palm of the hand without the fingers goes twice into the foot without the toes.

If you hold your hand with its five fingers extended and close together you will find that it is as wide as the maximum width of the foot, that is where it is joined to the toes.

And if you measure from the point of the ankle on the inside to the end of the big toe, you will find that this measure is as long as the whole hand.

From the top of the joint of the foot to the top of the insertion of the toes is as far as from the commencement of the hand to the point of the thumb.

The smallest width of the hand is equal to the smallest width of the foot between its joining with the leg and the commencement of the toes.

The width of the heel at its under side is equal to the thickness of the arm where it joins the hand, and also to the leg where it is thinnest viewed in front.

The length of the longest toe from where it begins to be divided from the big toe to its extremity is the fourth part of the foot, that is from the centre of the ankle bone on the inner side to its tip; and it is equal to the width of the mouth. And the space that there is between the mouth and the chin is equal to that between the knuckles of the three middle fingers and their first joints, when the hand is extended, and equal to the [distance from] the joint of the thumb to the beginning of the nail when the hand is extended, and it is a fourth part of the hand and of the face.

The space between the inner and outer extremities of the poles of the feet called the heels or ankles or bands of the feet, *a b*, is equal to the space between the mouth and the lachrymatory duct of the eye.

Quaderni VI 9 r.

The big toe is the sixth part of the foot, measuring it in profile on the inside, where this toe springs, from the ball of the sole of the foot towards its extremity *a b*; and it is equal to the distance from the mouth to the bottom of the chin. If you are doing the foot in profile from the outside make the little toe begin three quarters up the length of the foot, and you will find the distance that there is from the beginning of this toe to the farthest projection of the big toe.

Quaderni VI 9 v.

Width across shoulders one quarter of the whole. From the joint of the shoulder to the hand one third, from the line of the lip to below the shoulder-blade is one foot.

From the top of the head to the bottom of the chin one eighth. From the commencement of the hair to the chin is one ninth of the distance there is from this commencement to the ground. The greatest width of the face is equal to the space between the mouth and the commencement of the hair, and it is one twelfth of the whole height. From the top of the ear to the top of the head is equal to the distance from the bottom of the chin to the lachrymatory duct of the eyes. And equal to the distance from the point of the chin to that of the jaw, and it is the sixteenth part of the whole. The bit of cartilage '*pincierolo*' which is within the hole of the ear towards the nose is half way between the nape of the neck and the eyebrow.

The greatest thickness of a man from the breast to the spine goes eight times into the height and is equal to the space between the chin and the crown of the head.

The greatest width is at the shoulders and this goes four times.

The breadth of the neck in profile is equal to the space there is from the chin to the eyes, and equal to the space from the chin to the jaw, and it goes fifteen times into the whole man.

The arm bent is four heads.

The arm from the shoulder to the elbow in bending increases its length, that is the length from the shoulder to the elbow; and this increase is similar to the thickness of the arm at the wrist when you see it in profile, and similar to the distance from the bottom of the chin to the line of the mouth. And the thickness of the two middle fingers of the hand, and the width of the mouth, and the distance from where the hair begins on the forehead to the crown of the head — these things that I have mentioned are similar to each other, but not similar to the above named increase in the arm.

The arm from the elbow to the hand never increases when it is bent or straightened.

The arm when bent will measure twice the head from the top of the shoulder to the elbow, and two from this elbow to where the four fingers begin on the palm of the hand. The distance from where the four fingers begin to the elbow never changes through any change of the arm.

The lesser thickness of the leg as seen in front goes into the thigh three times.

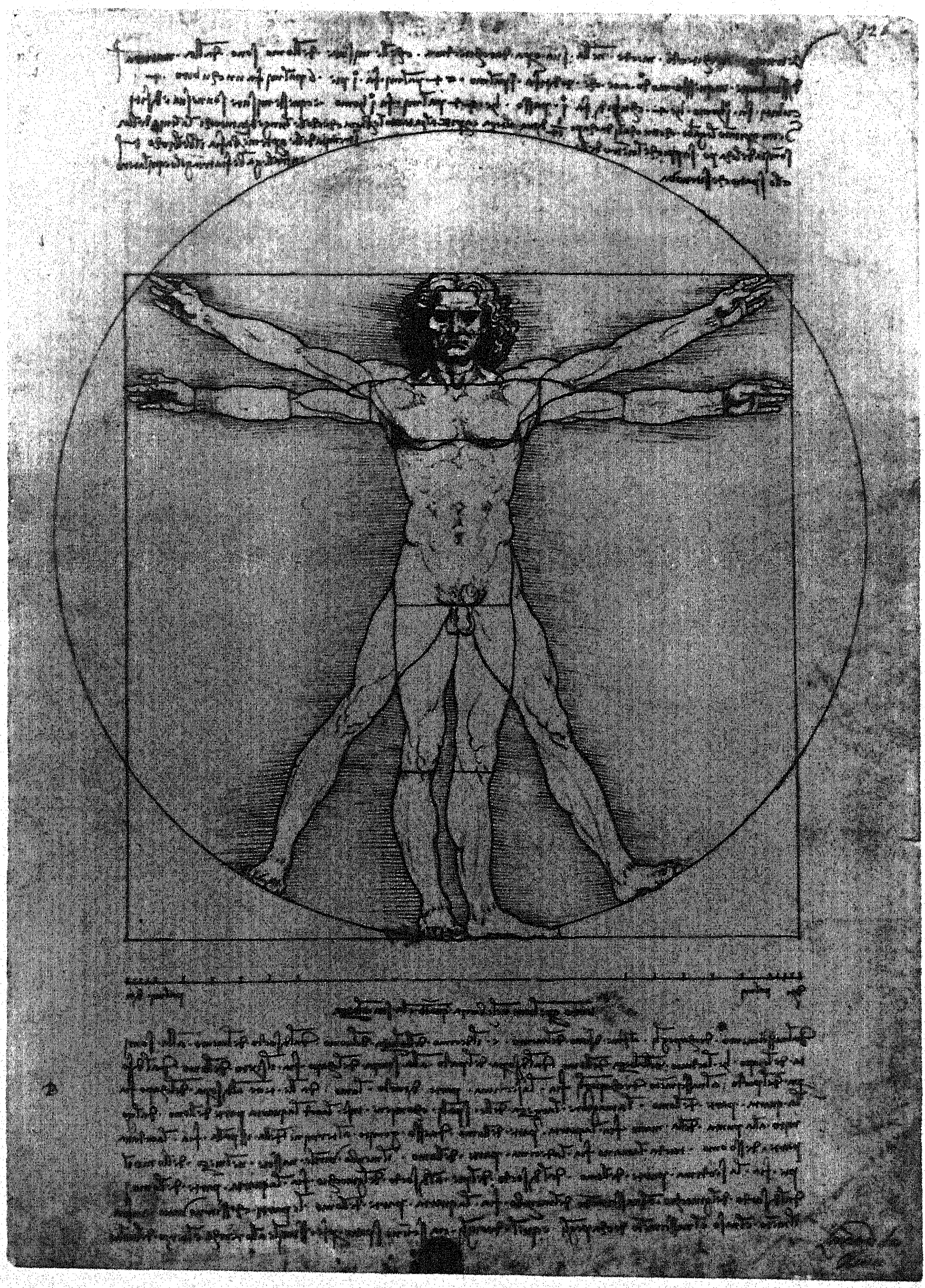
The thickness of the arm at the wrist goes twelve times into the whole arm, that is from the tips of the fingers to the shoulder-joint, that is three into the hand and nine into the arm.

The minimum thickness of the arm in profile, *m n*, goes six times from the joint of the hand to the dimple of the elbow extended, fourteen times into the whole arm, and forty-two times into the whole man.

The maximum thickness of the arm in profile is the same as the maximum thickness of the arm in front. But the one is placed in the third of the arm from the joint to the breast, the other in the third from the joint to the hand.

Quaderni VI 10 r.

A man is the same width below the arms as at the hips.



HUMAN PROPORTIONS

Accademia, Venice

[Text: I. 224-5]

A man's width across his hips is the same as the distance from the top of the hips to the bottom of the buttocks when he is standing equally balanced on both his feet; and it is the same distance from the top of the hips to the joining of the shoulders. The waist or the part above the hips will be half way between the joining of the shoulders and the bottom of the buttocks.

Quaderni VI 11 r.

The maximum thickness of the calf of the leg is in the third of its height *a b*, and it is a twentieth part larger than the maximum breadth of the foot.

When a man lies down his height is reduced to a ninth.

The thickness of the thigh in front is equal to the greatest breadth of the face as seen, that is two-thirds of the distance from the chin to the crown of the head.

I would know how much one increases when raising one's self on tip-toe; and when bending how much *p q* decreases, and how much *n q* increases; and so also with the bend of the foot.

Quaderni VI 11 v.

The minimum thickness of the leg in front goes eight times from the sole of the foot to the joint of the knee, and it is the same as the arm in front at the wrist, and as the maximum length of the ear and the three spaces in which the face is divided; and this breadth goes four times from the wrist to the point of the elbow.

The foot is as broad as the width of the knee between *a b*; the patella is as broad as the leg between *r s*.

From the tip of the longest finger to the shoulder-joint is four hands, or, if you prefer it, four heads.

The minimum thickness of the leg, as seen from the side, goes six times from the sole of the foot to the joint of the knee, and it is equal to the space between the corner of the eye and the orifice of the ear, and to the maximum thickness of the arm as seen from the side, and to that from the lachrymatory duct of the eye to the attachment of the hairs.

Quaderni VI 12 r.

Strong nudes will seem muscular and thick.

Those who are of little strength will be flabby[1] and thin.

Quaderni VI 14 r.

The architect Vitruvius states in his work on architecture that the

[1] MS. *laciertoso*.

measurements of a man are arranged by Nature thus: — that is that four fingers make one palm, and four palms make one foot, six palms make one cubit, four cubits make once a man's height, and four cubits make a pace, and twenty four palms make a man's height, and these measurements are in his buildings.

If you set your legs so far apart as to take a fourteenth part from your height, and you open and raise your arms until you touch the line of the crown of the head with your middle fingers, you must know that the centre of the circle formed by the extremities of the outstretched limbs will be the navel, and the space between the legs will form an equilateral triangle.

The span of a man's outstretched arms is equal to his height.

From the beginning of the hair to the end of the bottom of the chin is the tenth part of a man's height; from the bottom of the chin to the crown of the head is the eighth of the man's height; from the top of the breast to the crown of the head is the sixth of the man; from the top of the breast to where the hair commences is the seventh part of the whole man; from the nipples to the crown of the head is a fourth part of the man. The maximum width of the shoulders is in itself the fourth part of a man; from the elbow to the tip of the middle finger is the fifth part; from this elbow to the end of the shoulder is the eighth part. The complete hand will be the tenth part. The penis begins at the centre of the man. The foot is the seventh part of the man. From the sole of the foot to just below the knee is the fourth part of the man. From below the knee to where the penis begins is the fourth part of the man.

The parts that find themselves between the chin and the nose and between the places where the hair and the eyebrows start each of itself compares with that of the ear, and is a third of the face.

Venice Academy R 343

VIII

Medicine

'Medicine is the remedying of the conflicting elements: sickness is the discord of the elements infused in the living body.'

'You know that medicines when well used restore health to the sick: they will be well used when the doctor together with his understanding of their nature shall understand also what man is, what life is, and what constitution and health are. Know these well and you will know their opposites; and when this is the case you will know well how to devise a remedy.'

C.A. 270 r. c

TO BREAK A STONE IN THE BLADDER

Take the shell of a filbert, date stones, saxifrage, nettle seed in equal quantities, and make of them a fine powder and mix it with your food after the manner of spice, or take it if you wish in the form of syrup made with white wine which has been warmed.

Also asparagus or privet or a decoction of red chick peas.

C.A. 270 v. b

Medicine is the remedying of the conflicting elements: sickness is the discord of the elements infused in the living body.

Tr. 6 a

Anyone who suffers from seasickness should drink the sap of wormwood.

Tr. 44 a

Every man desires to acquire wealth in order that he may give it to the doctors, the destroyers of life; therefore they ought to be rich.

F 96 v.

Make them give you their diagnosis and treatment in the case of Sancto and of the other and you will see that men are chosen as physicians for diseases which they do not know.

B.M. 147 v.

Strive to preserve your health; and in this you will the better succeed in proportion as you keep clear of the physicians, for their drugs are a kind of alchemy concerning which there are no fewer books than there are medicines.

Fogli A 2 r.

IX

Optics

'These are the miracles — forms already lost mingled together in so short a space, it can recreate and reconstitute by its dilation.'

Why nature did not make a uniform power in the visual faculty:

Nature has not made a uniform power in the visual faculty but has given this faculty greater power in proportion as it is nearer to its centre, and this it has done in order not to break the law given to all other powers which have more potency in proportion as they approach nearer to this centre.

And this is seen in the act of the percussion of any body, and in the supports of the arms of the balance where the gravity of the weight is lessened as it draws nearer; it is seen in the case of columns walls and pillars; it is seen with heat and in all the other natural powers.

Why nature made the pupil convex, that is raised up like part of a ball:

Nature has made the surface of the pupil situated in the eye convex in form so that the surrounding objects may imprint their images at greater angles than could happen if the eye were flat.

D I r.

OF THE EYE

Why the rays of luminous bodies become larger in proportion as they are farther removed from their source:

The rays of luminous bodies increase the more as they proceed farther from their beginnings. This is proved thus: let *a* be the luminous body of which the image is impressed in the pupil of the eye of the beholder and let us say that *c* is the pupil upon which the impression is made, and the same image is impressed also upon the thick part of the upper lid *b* and on the lower lid *o*, and from the upper and lower lids the second images are reflected in the pupil of the eye *c*. But as regards the pupil that receives the three said images which are divided by the images of the lids of the eyes (in this instance almost closed), it seems that the images of the luminous bodies impressed on the thick parts of the lids of the eyes are as though actually subdivided and that these divisions are pyramidal because the intervals between the lids are also pyramidal. And since to the pupil which receives these three images it seems that the two images which rebound upon it from the lids are joined together above and below to the image of the centre which represents the luminous body, it seems to this pupil that the image *b* is in *a n*, and the image *o*

appears to be in *a m*, and that the two images are divided by the image of the luminous body *a*.

And since in closing together the rims of the eyelids it is necessary that the watery substance continually keeps the lids moistened as they rub upon the eye, so this moisture fills up the angle that is produced by the contact made by the lids with the pupil of the eye, and the surface of this watery substance is concave, as is proved in the fourth of the eighth of water where it states that 'the contact which water makes with its moist bank will always have its surface concave', and that 'if this bank is dry the surface of the water that borders upon it will be convex'.

This angle therefore finding itself created by the contact between the lid of the eye and its pupil will have the surface of the aqueous humour filling up this angle of the concave figure. And since every concave mirror shows within the pyramidal concourse of its rays the image of its object upside down, it follows therefore that the weights or lids of the eyes mirrored within this hollow together with the image of the light will show these lids inverted; and this is the reason why when the pupil is within the concourse of the pyramidal rays of the concave mirror the pupil sees the pyramids formed by the rays of the spaces between the lids upside down.

And this is the true reason of the rays of luminous bodies which the more they extend seem to approach nearer to the eye. Such a demonstration however ought to be divided into its parts in order to render it more intelligible, setting out first its conceptions and other propositions necessary for such proof.

D I V.

Whether the images of objects are taken by the visual faculty to the surface of the eye or whether they pass within it:

The glasses of spectacles show us how the images of objects pause at the surface of these glasses and then by bending themselves penetrate from this surface to the surface of the eye, from which surface it is possible for the eye to see the shapes of the aforesaid objects.

This is proved to be possible because this surface is the common boundary between the air and the eye, in that it separates the vitreous humour from the air and separates the air from this vitreous humour. And if we wish to affirm that the images of the objects stop on the surfaces of the spectacles one might say that in the spectacles of old men the object would seem much larger than the reality, and but for the

interposition of this glass between the eye and the object this object would show itself of its natural size; therefore [this not being so] is a clear proof that the convergence of the images of any object which is cut by the interposition of transparent bodies will impress itself on the surface of these bodies and will there create a new convergence which will lead the images of these objects to the eye.

D 2 r.

How the images of any object whatsoever which pass to the eye through some aperture imprint themselves on its pupil upside down and the understanding sees them upright:

The pupil of the eye which receives through a very small round hole the images of bodies situated beyond this hole always receives them upside down and the visual faculty always sees them upright as they are. And this proceeds from the fact that the said images pass through the centre of the crystalline sphere situated in the middle of the eye; and in this centre they unite in a point and then spread themselves out upon the opposite surface of this sphere without deviating from their course; and the images direct themselves upon this surface according to the object that has caused them, and from thence they are taken by the impression and transmitted to the common sense where they are judged. This may be proved thus: — let *a n* be the pupil of the eye *k h*, and let *p* be a small round hole made in the paper with the fine point of a style, and let *m b* be the object placed beyond this opening. I maintain that the upper part of this object cannot come to the upper part of the pupil of the eye through the straight line *m a* because at *v* its passage is impeded by the interposition of the paper. But this upper extremity *m* passes in a straight course through the hole to *n* the lower part of the pupil, or you would say of the crystalline sphere, and from there it directs its course to the centre of this sphere, then rises to the upper part of the opposite side and from there as has been said it runs to the common sense.

D 2 v.

Why the mirror in its images of objects changes the right side to the left and the left to the right:

The image of every object is changed in the mirror so that its right side is opposite to the left of the object reflected and similarly the left to the right. This is of necessity the case because every natural action is performed by nature in the shortest manner and the briefest time possible. Let *a b* be a face which sends its image to the mirror *c d*, this

face will have another face in this mirror turned towards it, so that it will have the left eye *c* opposite to the right *a* and similarly the right eye *d* will be opposite to the left eye *b*.

And if it should be urged by the opponent that the right eye of the image was opposite to the right of the object we might project the lines from the right eye of the image to the right eye of the object and similarly from the left to the left, these lines being *a d* and *b c* which are seen to intersect; and it is proved that in all cases of lines intersecting the right extremity of the one is always opposite to the left extremity of the other, and this result is not produced by the shortest line because the diagonal of a square is always longer than its side, and here *a d* is the diagonal of the square *a b c d* of which *a c* is one of its sides; and thus is concluded what was necessary in order to prove such a result.

And this effect in the mirror would be as though someone who was looking at you, someone that is who has the left eye opposite to your right, were as by a miracle transposing left and right as is the case with letters used in stamping and wax which takes the impress of the cornelian.

D 4 r.

OF THE HUMAN EYE

The pupil of the eye changes to as many different sizes as there are differences in the degrees of brightness and obscurity of the objects which present themselves before it:

In this case nature has provided for the visual faculty when it has been irritated by excessive light by contracting the pupil of the eye, and by enlarging this pupil after the manner of the mouth of a purse when it has had to endure varying degrees of darkness. And here nature works as one who having too much light in his habitation blocks up the window half-way or more or less according to the necessity, and who when the night comes throws open the whole of this window in order to see better within this habitation. Nature is here establishing a continual equilibrium, perpetually adjusting and equalising by making the pupil dilate or contract in proportion to the aforesaid obscurity or brightness which continually presents itself before it. You will see the process in the case of the nocturnal animals such as cats, screech-owls, long-eared owls and suchlike which have the pupil small at midday and very large at night. And it is the same with all land animals and those of the air and of the water but more, beyond all comparison, with the nocturnal animals.

And if you wish to make the experiment with a man look intently

at the pupil of his eye while you hold a lighted candle at a little distance away and make him look at this light as you bring it nearer to him little by little, and you will then see that the nearer the light approaches to it the more the pupil will contract.

Whether the eye sees bright and dark things at the same time:

The crystalline humour which dwells within the pupil is condensed on meeting with shining things and becomes rarefied on meeting with dark things; and the truth of this is shown in closing the eye, for then the images retained which were of bright things seem dark and those of dark things seem bright; and this happens more with weak eyes than with those that are strong, and of this I will speak more fully in its place.

There follows the discourse concerning the eye of the nocturnal animals which see better by night than by day. And this comes about because the size of the eyes is greater than the whole of the brain, especially in the case of the long-eared and short-eared owls, the white owls, the little owls and horned owls and suchlike creatures, but it does not occur with man who has a greater brain in proportion to the size of his eyes than any other animal that lives on land, and can see but little light after day-time.

D 5 v.

There follows concerning the eye of the nocturnal animals which see more by night than by day, and this arises in great part from the fact that as was said before there is a much greater difference between the size of the pupil when dilated and contracted than there is in the case of the animals which are active by day, for if the pupil of the man doubles its diameter at night, that is to say it is increased to four times what it is by day, the diameter of the pupil of the horned owl or the long-eared owl is increased to ten times what it is by day which amounts to saying that the pupil is a hundred times as large as it is by day.

Furthermore the ventricle situated in the brain of man called the imprensiva is more than ten times the whole of the eye of man, and of this the pupil in which the sight has its origin is less than a thousandth part; and in the case of the long-eared owl the pupil at night is considerably larger than the ventricle of the imprensiva situated in its brain. From this it follows that the imprensiva in man is greater in proportion to the pupil, it being in fact ten thousand times as great whereas in the case of the horned owl they are almost equal.

And this imprensiva of man in comparison with that of the long-eared owl is like a great room which receives the light through a small hole as compared with a small room which is entirely open. For within the great room there will be night at midday and in the small one which is open there will be day at midnight when the weather is not overcast. And herewith may be shown the workings of the most powerful causes by means of the anatomy of the eyes and the imprensiva of these two animals, namely of man and of the horned [long-eared?] owl.

That object will seem of greater radiance and size which is seen by a larger pupil. One may make an experiment of this with our eyes by making as small a hole as possible in a sheet of paper and then bringing it as near as possible to the eye, and if then you look at a star through this hole you are only making use of a small part of the pupil, which sees this star with a wide space of sky round it and sees it so small that hardly anything can be less. And if you make the hole near to the edge of the said paper you will be able to see the same star with the other eye at the same time and it will appear to you to be large, and thus in the said time you will see the one star twice with your two eyes and once it will be small and the other time large. Further you will be able to see the whole body of the sun and with only a moderate amount of radiance, for the more its size is diminished so in proportion is its radiance as was set forth above. And from this it arises that the large pupils (luce?) see but little of the daylight because the excess of radiance impedes their vision.

D 5 r.

The image of the sun is unique in all the watery sphere which sees and is seen by this sun, but it seems divided into as many parts as are the eyes of the animals which from different positions behold the surface of the water.

This that is set forth is proved because however far the eyes of the navigators carried by ships may move through the universe they behold at the same time the image of the sun through all the waters of their hemisphere in all the movements made in all the aspects.

If the eye was as large as the sphere of the water it would see the image of the sun covering a great part of the ocean.

This is shown because if you were to move yourself upon a bridge from which you can see the image of the sun in the waters of its river, and you move yourself about twenty-five braccia, you will see the image of the sun move just as far in the surface of the said water. And so if

one were to put together all the images that are seen during this movement you would have a single image which would be of the shape of a fiery beam. Now imagine yourself to make a circle of which this beam is the diameter, and that the whole of this circle is full of these images, without doubt you would see one image the diameter of which would be twenty-five braccia; now you must understand that if a pupil were to have its diameter the same twenty-five braccia it would without moving itself see in the same water an image of the sun which would revolve in seventy-eight braccia and four sevenths.

If through the long distance at which the eye was from the watery sphere the watery sphere should become diminished to the size of an ordinary image of the sun, as is shown in perspective, you would see the sphere of this water which is seen by the sun was a single image of this sun.

This is proved in perspective how things remote from the eye even when they are exceedingly large seem very small in bulk, and this may be seen without any elaborate demonstration if you raise your eyes to the sky when it is bedecked with stars, for you will see there many stars which are many times larger than the earth and yet appear very small on account of their great distance, and the light which you perceive in them is not their own but is merely an image of the sun reflected in them. For of themselves these stars have no light, but they have a surface like the watery sphere suitable for receiving and giving back the light of the sun which is reflected in them.

D 6 r.

OF THE HUMAN EYE

The pupil of the eye has a power of vision all in the whole and all in each of its parts; and an object placed in front of the eye which is less than its pupil does not occupy the place in the eye of any other distant object, and although it is compact it serves the function of a transparent object.

Here the adversary says that the power of vision is reduced to a point and that it follows from this that every object placed in front of the pupil which is greater than this point will occupy the attention [of the eye]. I say in reply to him that if it were true that the power of vision was reduced to a point, the convexity of the eye which with its parts is turned towards a great part of the universe which is opposite to it would not be able to have such a curve unless it were equidistant from this point and its surface were cut at an equal distance from this point, so that each of

them with the same actual proportions correspond in the points of the angles to the proportions of the images of the bodies that meet at this point.

To such a one it is necessary to appeal to experience and then to show this experience to be conclusive; and first as regards experience if you place in front of the pupil the thick end of a sewing needle of medium width as near as possible you will see that the perception of any object placed behind this needle at however great a distance will not be interfered with.

What I say is entirely borne out by experience and necessity confirms it; for if this visual faculty be reducible to a point every object however small placed in front of it would occupy the attention of a great part of the heaven, for if a great part of the heaven transmits the images of its stars to the pupil an object placed near to it and equal to the half of its diameter would cover almost the half of the sky. This is why nature in order that nothing may be lacking for the eyes of the animals has caused this pupil to have the smallest number of obstructions and less than may seem possible, among which the faculty of vision would be the greatest because as has been said every object however small set over against it would take up a great amount of space.

Moreover, experiment proves that sheets of canvas made out of thick horse-hair and placed in front of the eyes do not cover anything behind them and conceal it the less in proportion as they are nearer to the eye, whereas if the faculty of vision were focused in a point the nearer to it were the horse-hairs, the larger would be the space that they would occupy. As therefore experience demonstrates the contrary it is true that the visual faculty is infused through the whole pupil and makes use of every part of it and looks beyond this horse-hair encompassing it and penetrating through the thickest part of it, and of necessity forming pyramids near the aforesaid horse-hairs.

D 6 V.

Every concave place will appear darker if seen from the outside than from within.

And this comes about because the eye that is outside in the air has the pupil much diminished, and that which is situated in a dark place has the pupil enlarged and with the lesser eyeball the power is diminished, and in like manner this power increases in proportion to the increase of its pupil, and when the pupil is of feeble power every small obscurity

will appear dark, and as it grows in power every great obscurity will appear lit up.

Excess of light injures the eye and in order to protect it from being injured in this way the visual faculty takes the help which any one gets who shuts part of a window in order to lessen the excessive brightness which the sun produces in his dwelling.

D 7 r.

Why the right object does not seem the left to the eye:

The images of the objects in the eye when making their entry into the eye deflect their rays in a way that is proved in perspective when these images pass from the density of the water to the thinness of the air. But to come back to the proposition that the right object does not appear the left in the eye, we see clearly by experiment that the images which penetrate into the vitreous humour by the pupil of the eye meet together in the sphere of the crystalline humour, as to which two considerations present themselves, namely whether the visual faculty resides in it or at the extremity of the optic nerve, which extremity catches these images and transmits them to the common sense as do the nerves of the sense of smell. And if this faculty resides in the centre of the crystalline humour it catches the images with its surface, and they are referred there from the surface of the pupil, where the objects are mirrored or reflected there from the surface of the uvea which bounds and clothes the vitreous humour which has darkness behind its transparency, just as behind the transparency of the glass we find the darkness of the lead in order that objects may be the better mirrored in the surface of this glass. But if the visual faculty is in the centre of the crystalline sphere all the objects which are given it from the surface of the pupil of the eye will appear in the true position in which they are, and will not change from the right to the left and will seem larger, as is shown in perspective. And if this crystalline sphere takes these images reflected from the concavity of the uvea it will take them upright although the uvea is a concave mirror, and it will take them upright because the centre of the crystalline sphere is concentric with the centre of the sphere of the uvea.

It is true that the images which pass to this uvea as they are outside the eye pass to it through the centre of the crystalline sphere, and having arrived at the uvea they become inverted as also are those which pass to the uvea without passing through this humour. We may surmise therefore, admitting this visual faculty to reside at the extremity of the optic

nerve, that from here it may be seen in the crystalline sphere that all the objects caught by it are upright, for it takes those that were inverted in the uvea and inverts them once again, and consequently this crystalline sphere presents the images upright which were given to it inverted. To such master in optics one would perhaps say that the spherical surface of the crystalline sphere united to the sphere of the vitreous humour does not change its nature, and it is as though the whole was vitreous, and that for this reason the vitreous sphere does not fulfil the same function as it would if it were surrounded by the air. The reply to this however is that this result cannot occur because a ball of crystal placed in water fulfils the same function as it does in air. D 7 V.

The images of the objects placed before the eye pass to the vitreous sphere by the gate of the pupil, and they intersect within this pupil in such a way that the vitreous sphere is struck on its left side by the right ray of the right sphere, and it does the same on the opposite side; afterwards it penetrates this vitreous sphere, and the rays contract and find themselves much closer together when they are on the opposite side of this sphere than when they strike it in the beginning.

And this process of contraction proceeds from the fact that the rays of the images approach the perpendicular when they pass from the thin to the dense, and that the albugineous humour is here much thinner and more subtle than the space enclosed by the surface of the vitreous sphere. Afterwards (the image) ought to enlarge as it returns into this albugineous humour, but it does not follow this rule because it is constrained to obey the nature of the vitreous sphere from whence it proceeds rather than that of the albugineous humour through which it passes.

And this is why it makes a pyramid as it issues forth from the vitreous sphere and passes through the albugineous humour, and intersects its sides at the point *f*; and passes to the visual faculty *g* at the extremity of the optic nerve *g s*.

Of the intersection of the images of the objects received by the eye within the albugineous humour:

Experience which shows that the objects transmit their images or likenesses intersected within the eye in the albugineous humour shows [what happens] when the images of the illuminated objects penetrate through some small round hole into a very dark habitation. You will then

receive these images on a sheet of white paper placed inside this habitation somewhat near to this small hole, and you will see all the aforesaid objects on this paper with their true shapes and colours, but they will be less, and they will be upside down because of the said intersection.

These images if they proceed from a place that is lit by the sun will actually seem painted upon this paper, which should be very thin and seen in reverse; and the said hole should be made in a very thin sheet of iron. Let *a b c d e* be the said objects lit by the sun, *o x* be the façade of the dark habitation in which is the said hole at *n m*, *s t* the said paper where the rays of the images of these objects inverted are cut, for as their rays are straight *a* which is right becomes left at *k* and *e* which is left becomes right at *f*, and so it is within the pupil.

D 8 r.

Why the point of the style when placed across the pupil of the eye throws a great shadow upon the object:

When the point of the style is placed crosswise before the pupil of the eye, the diameter of its thickness being considerably less than the diameter of this pupil, it will occupy more or less space against other objects in proportion as it is nearer or more remote from the eye; and this occupation of space will obscure but will not prevent the passage of the images of the aforesaid objects.

D 9 r.

Why the rays of the luminous bodies increase in proportion to the space that is interposed between them and the eye:

The lengths of the rays created by the luminous bodies increase with the increase of the space that is interposed between these bodies and the eye. It is necessary here first to define what are the rays of the luminous bodies, and whether they have their origin in the eye which looks at these bodies or in fact proceed from these luminous bodies, and if we should conclude that they proceed from the eye it is necessary to define why and in what manner.

Why the luminous bodies show their contours full of straight luminous rays:

The rays which reveal the contours of luminous bodies do not derive their origin from these bodies but from their images which imprint themselves upon the thickness of the lids of the eyes that look upon these bodies. This we learn in the first place by the inductive method which

teaches us that the eye when wide open does not show us such rays round luminous bodies, and that if the image of a star or other light should pass to the eye through the smallest perforation made in the paper placed before the eye, such luminous [images] will always be without rays. But the real proof is shown by the ninth of Perspective where it is stated: — the angle of the incidence is always equal to the angle of the reflection, — therefore, the rays, which seem as though they extend from the luminous body to make contact with the eye that beholds it, start when the eye, being almost closed up, looks through the narrow crack that intervenes between the eyelids, at that luminous body of which the image is reflected in the thick parts of the lids which end these coverings, and after making this impress is reflected on the pupil of the eye; which pupil receives three images from the same luminous body, namely two in the thick parts of the lids of the coverings of the eye and one in the pupil, and through these three images being very near one to another, they seem to the eye to be continuous and joined to the image of the pupil.

And the proof that experience offers us to confirm this proposition is shown when you raise or lower the face while keeping the eye firmly fixed upon the luminous body; for as the face is raised the eye will lose all the lower rays of this luminous body. This comes about because *the image of this luminous body does not proceed to imprint itself in the thick part of the lower lid of this eye*[1]; where the luminous body does not see it, it cannot there imprint its image, and where the falling ray does not strike it does not produce the reflex ray, and for this reason the pupil does not take it. And so it will happen when the face is lowered, for then the thick part of the upper covering of the eye neither sees nor is seen by that luminous body, for which cause the image as has been said cannot imprint itself there, and in consequence the eye cannot there discern what is not there; but it sees this image in the lower covering, and this lid sees and is seen by the luminous body, and thus we have proved our intent.

The adversary says that the ray bends because it goes to the sense from the thin to the dense.

D 9 V.

The images of the objects infused in the opposite air are all in all this air and all in every part of it. This is proved: —

Conception of the objects. All that air sees the object opposite to itself which is seen by the same object.

[1] The words in italics are crossed out in the manuscript.

This is proved by the third of this which says that all the visions made in the same quality of air are rectilinear.

Therefore since it is possible to draw a straight line from the eye to each part of the air seen by this eye this vision is rectilinear. And this is also proved by what Aristotle says:—'every natural action is made in the briefest way possible'. The vision therefore will be made by the shortest line, that is by a straight line.

OF THE IMAGES OF THE OBJECTS INFUSED THROUGHOUT THE AIR

The objects have their images infused in all the air that is seen by these objects: which images are all in all the above-mentioned air and are all in every part of it.

How the eye does not know the boundary of any body:

The eye will never be capable of [perceiving] the true boundary of the figures of any body when they show up against the far distance. This may be proved: let *a b* be the pupil of the eye and *c p* the body placed opposite to the eye of which we have noted that *c* is the upper extremity, and let *n m* be the background against which this extremity ought to be perceived by the eye. I maintain that it is not possible to ascertain in what part of this background the extremity of this body terminates, and this is proved by the help of the third [section] of this [treatise] in which it is stated that the faculty of vision is not in a point as the painters who have treated of perspective would have us to suppose, but is all in the whole of the pupil into which the images of the objects penetrate, and within the eye in a larger space than that occupied by this pupil. But these images are the more clearly to be perceived in proportion as they are nearer to the centre of this faculty [of vision] located in the said space and the less clearly in proportion as they are farther removed from this centre.

If therefore the visual faculty *a b* takes in the extremity of the object *c* the centre line of the visual faculty *r* sees *c* in the part of the background *f*, and the upper extremity of this visual faculty that is *s* sees *c* in the background *h* and the lower part of the visual faculty sees *c* in the background *d*; and thus it goes spreading itself through the whole background *d h*; and through this such extremity is not known to the eye because the sense of the visual faculty is spread through all this faculty which offers to the judgment a vague perception of this extremity *c*, and

so much more or less as it is nearer or more remote from this centre line of the visual faculty, and so much more or less as it is more remote or nearer to the eye.

D 10 V.

A stone thrown through the air leaves in the eye which sees it the impression of its movement, and drops of water do the same as they descend from the clouds when it rains.

C.A. 79 r. c

OF THE NATURE OF SIGHT

I say that sight is exercised by all animals through the medium of light; and if against this any one should instance the sight of nocturnal animals, I would say that these in exactly the same way are subject to the same law of nature. For, as one may readily understand, the senses, when they receive the images of things, do not send forth from themselves any actual power; but on the contrary the air which is between the object and its sense, serving as a medium, incorporates within itself the images of things, and by its own contact with the sense presents them to it, if the objects either by sound or smell project themselves to the eye or the nose by virtue of their incorporeal powers. Here the light is not necessary, nor is it made use of.

The forms of objects do not enter into the air as images unless they are luminous; this being so, the eye cannot receive the same from that air which does not contain them, but only touches their surface.

If you wish to speak of the many animals which hunt their prey by night, I answer that when that small amount of light sufficient for them to see their way fails them, they avail themselves of their powers of hearing and smell, which are not impeded by the darkness, and in which they are far in advance of man. If you watch a cat in the day-time leaping among a lot of pieces of crockery you will see that these will remain whole; but if it does the same by night it will break a considerable number. Night birds do not fly unless the moon is shining either full or in part, but their time of feeding is between the hour of sunset and the total darkness of the night.

No substance can be comprehended without light and shade; light and shade are caused by light.

C.A. 90 r. b

OF THE EYE

Since the eye is the window of the soul, the latter is always in fear of being deprived of it, to such an extent that when anything moves in

front of it which causes a man sudden fear, he does not use his hands to protect his heart, which supplies life to the head where dwells the lord of the senses, nor his hearing, nor sense of smell or taste; but the affrighted sense immediately not contented with shutting the eyes and pressing their lids together with the utmost force, causes him to turn suddenly in the opposite direction; and not as yet feeling secure he covers them with the one hand and stretches out the other to form a screen against the object of his fear.

Preamble to perspective — concerning the functions of the eye:

Consider now, O Reader, what trust can we place in the ancients who have set out to define the nature of the soul and of life, — things incapable of proof, — whilst those things which by experience may always be clearly known and proved have for so many centuries either remained unknown or have been wrongly interpreted.

The eye which thus clearly offers proof of its functions has even down to our own times been defined by countless writers in one way, but I find by experience that it acts in another.

C.A. 119 v. a

All the images of the things set over against the eye converge in shining lines on the surface of the eye; and these intersect on the surface of the eye at equal angles.

The atmosphere is all in all and all in every part of it filled with the images of the bodies which are enclosed within it.

C.A. 120 r. d

I find by experience that the black or almost black fringe of colour (colore crispo ovver rasposo) which appears round the pupil serves for no other purpose except to increase or diminish the size of this pupil; to increase it when the eye is looking towards a dark place; to diminish it when it is looking at the light or at a luminous thing.

And you should make the experiment of holding a light near to the eye, and make it when you are looking into the darkness and then turn the eye to this light, and you will be convinced by this experiment.

C.A. 125 r. a

If the object in front of the eye sends its image to it the eye also sends its image to the object, so of the object and of the image proceeding from it no portion is lost for any reason either in the eye or the object. Therefore we can sooner believe that it is the nature and power of this

luminous atmosphere that attracts and takes into itself the images of the objects that are within it than that it is the nature of the objects which transmits their images through the atmosphere.

If the object in front of the eye were to send its image to it the eye would have to do the same to the object, whence it would appear that these images were incorporeal powers. If it were thus it would be necessary that each object should rapidly become less; because each body appears as an image in the atmosphere in front of it, that is the whole body in the whole atmosphere and the whole in the part, and all the bodies in the whole atmosphere and all in the part, referring to that portion of it which is capable of receiving into itself the direct and radiating lines of the images transmitted by the objects. For this reason then it must be admitted that it is the nature of this atmosphere which finds itself among the objects to draw to itself like a magnet the images of the objects among which it is situated.

A proof how all the objects placed in one position are all in the whole of it and all in each part:

I maintain that if the front of a building or some piazza or field which is illuminated by the sun has a dwelling over against it, and in that part of the front which does not face the sun you make a small round hole, all the objects which are lit by the sun will transmit their images through this hole, and will be visible inside the dwelling on the opposite wall which should be made white. And they will be there exactly, but inverted; and if in different parts of the same wall you make similar holes you will produce the same effect in each.

Therefore the images of the illuminated objects are all everywhere on this wall and all in each of its smallest parts. The reason is this: we know clearly that this hole ought to give some light to this dwelling and the light which passes through it is caused by one or by many luminous bodies: if these bodies are of different colours and shapes the rays which make their images will be of different colours and shapes and so also will be the representations on the wall.

C.A. 135 v. b

The flea and the man can approach the eye and enter into it at equal angles. For this reason does not the judgment deceive itself in that the man does not seem larger than this flea? Enquire as to the cause.

C.A. 190 v. b

The greater the spherical body the less is the proportion of itself that it shows to the eye when the eye does not change its position.

C.A. 216 r. a

A proof of the manner in which glasses aid the sight:

Let *a b* be the glasses and *c d* the eyes, and suppose these to have grown old. Whereas they used to see an object at *e* with great ease by turning their position very considerably from the line of the optic nerves, but now by reason of age the power of bending has become weakened, and consequently it cannot be twisted without causing great pain to the eyes, so that they are constrained of necessity to place the object farther away, that is from *e* to *f*, and so see it better but not in detail. But through the interposition of the spectacles the object is clearly discerned at the distance that it was when they were young, that is at *e*, and this comes about because the object *e* passes to the eye through various mediums, namely thin and thick, the thin being the air that is between the spectacles and the object, and the thick being the thickness of the glass of the spectacles, the line of direction consequently bends in the thickness of the glass, and the line is twisted, so that seeing the object at *e* it sees it as though it was at *f*, with the advantage that the position of the eye with regard to its optic nerves is not strained and it sees it near at hand and discerns it better at *e* than at *f* and especially the minute portions.

C.A. 244 r. a

In just such proportion as the eye when it functions is nearer than the ear it will the more preserve the images of the objects imprinted upon it.

C.A. 250 r. a

Among the solar images preserved within the eye that which the eye has retained for a less time will appear more luminous.

C.A. 262 r. b

I say that the power of vision extends by means of the visual rays as far as the surface of bodies which are not transparent, and that the power possessed by these bodies extends up to the power of vision, and that every similar body fills all the surrounding air with its image. Each body separately and all together do the same, and not only do they fill it with the likeness of their shape, but also with that of their power.

Example

You see with the sun when it is at the centre of our hemisphere, how there are images of its form in all the parts where it reveals itself, and you

see how in all these same places there are also the images of its radiance, and to these must also be added the image of the power of its heat; and all these powers proceed from the same source by means of radiant lines which issue from its body and end in the opaque objects without it thereby undergoing any diminution.

The north star remains continually with the images of its power spread out, becoming incorporated not only in thin but in thick bodies, in those transparent and those opaque, but it does not on this account suffer any loss of its shape.

Confutation

Those mathematicians, then, who say that the eye has no spiritual power which extends to a distance from itself, since, if it were so, it could not be without great diminution in the use of the power of vision, and that though the eye were as great as the body of the earth it would of necessity be consumed in beholding the stars: for this reason they maintain that the eye takes in but does not send forth anything from itself.

Example

What will these say of the musk which always keeps a great quantity of the atmosphere charged with its odour, and which, if it be carried a thousand miles, will permeate a thousand miles with that thickness of atmosphere without any diminution of itself?

Or will they say that the sound which the bell makes on its contact with the clapper, which daily of itself fills the whole countryside with its sound, must of necessity consume this bell?

Certainly, it seems to me, there are such men as these — and that is all that need be said of them.

Is not that snake called lamia seen daily by the rustics attracting to itself with fixed gaze, as the magnet attracts iron, the nightingale, which with mournful song hastens to her death?

It is said also that the wolf has power by its look to cause men to have hoarse voices.

The basilisk is said to have the power by its glance to deprive of life every living thing.

The ostrich and the spider are said to hatch their eggs by looking at them.

Maidens are said to have power in their eyes to attract to themselves the love of men.

The fish called linno, which some name after St. Ermo, which is found off the coasts of Sardinia, is it not seen at night by the fishermen, shedding light with its eyes over a great quantity of water, as though they were two candles? And all those fishes which come within the compass of this radiance, immediately come up to the surface of the water and turn over, dead.

C.A. 270 V. C

If you take a light and place it in a lantern tinted green or other transparent colours you will see by experiment that all the objects which are illuminated by this light seem to take their colour from the lantern.

You may have also seen in churches how the light which comes through stained-glass windows assumes the colour of the glass of these windows. If this does not convince you, watch the sun at its setting when it shows itself red through the vapour, how it dyes red all the clouds which take their light from the sun.

Opinions

All these instances are given in order to prove how all things or certainly many things transmit the appearance of their powers together with the image of their form without any injury to themselves; and this also may happen with the power of the eye.

Contrary opinion

Furthermore if anyone wished to say that the eye was not adapted to receive like the ear the images of objects without transmitting some potency in exchange for these, this may be proved by the instance of the small hole made in a window which gives back all the images of the bodies which are opposite to it; therefore one may say that the eye does the same.

Refutation

If the small hole cited as an example without sending forth anything except its form without incorporeal power gives back to the house the images of objects in their colour and form and there inverts them, the eye would have to do the same so that everything seen would appear there inverted.

Proof to the contrary

The circle of the light which is in the middle of the white of the eye is by nature suitable to apprehend objects. This same circle has in it a point which seems black and this is a nerve bored through it which goes within to the seat of the powers charged with the power of receiving impressions and forming judgment, and this penetrates to the common sense. Now the objects which are over against the eyes act with the rays of their images after the manner of many archers who wish to shoot through the bore of a carbine, for the one among them who finds himself in a straight line with the direction of the bore of the carbine will be most likely to touch the bottom of this bore with his arrow; so the objects opposite to the eye will be more transferred to the sense when they are more in the line of the transfixing nerve.

That water which is in the light that surrounds the black centre of the eye serves the same purpose as the hounds in the chase, for these are used to start the quarry and then the hunters capture it. So also with this, because it is a humour that derives from the power of the imprensiva and sees many things without seizing hold of them, but suddenly turns thither the central beam which proceeds along the line to the sense, and this seizes on the images and confines such as please it within the prison of the memory.

C.A. 270 r. b

Why objects as they come upon the small surface of the eye appear large arises from the fact that the pupil is a concave mirror; and so one sees for example with a glass ball filled with water that anything placed at the side either inside or outside appears larger.

C.A. 309 r. b

Nothing can be seen that does not transmit its image through the air.

Therefore nothing that is spiritual or transparent can see anything set over against it, for this requires that it have within itself a thick opaque instrument and being thus it is not termed a spirit.

Prove how nothing can be seen except through a small fissure, through which the atmosphere passes filled with the images of objects that intersect within the thick and opaque sides of the above-mentioned fissures. And for this reason nothing which has not substance can discern either the shape or colour of any object, seeing that it is necessary that there should be a thick opaque instrument in order that through the

fissure in it the images of the objects may assume their colours and shapes.

C.A. 345 r. b

Seeing that the images of the objects are all spread throughout all the air which surrounds them, and are all in every point of the same, it must be that the images of our hemisphere enter and pass together with those of all the heavenly bodies through the natural point in which they merge and become united, by mutually penetrating and intersecting each other, whereby the image of the moon in the east and the image of the sun in the west at this natural point become united and blended together with our hemisphere.

O marvellous Necessity, thou with supreme reason constrainest all effects to be the direct result of their causes, and by a supreme and irrevocable law every natural action obeys thee by the shortest possible process!

Who would believe that so small a space could contain the images of all the universe? O mighty process! What talent can avail to penetrate a nature such as these? What tongue will it be that can unfold so great a wonder? Verily, none! This it is that guides the human discourse to the considering of divine things.

Here the figures, here the colours, here all the images of every part of the universe are contracted to a point.

O what point is so marvellous!

O wonderful, O stupendous Necessity thou by thy law constrainest all effects to issue from their causes in the briefest possible way!

These are the miracles, . . . forms already lost, mingled together in so small a space, it can recreate and reconstitute by its dilation.

How it may be that from indistinct causes there may issue effects manifest and immediate, as are the images which have passed through the aforesaid natural point.

Write in thy Anatomy what proportion there is between the diameters of all the lenses of the eye, and the distance from these to the crystalline lens.

C.A. 345 v. b

The point is in itself an indivisible part, separated from and similar to all, and possessing the capacity of all, and all the indivisible parts are similar to the one and are such as may all be contained in that one, as is shown by experience in the points of the angles of the air-holes, for

when the solar rays have passed through these the angles become the termination and point of the primitive and derived pyramid.

This derived pyramid although of less force is none the less capable of going a long way enlarging and expanding itself with the concourse of its rays much more than the primitive.

And this same phenomenon may be seen in concave mirrors, for these after taking the solar rays according to their capacity lead them in pyramid fashion to the divisible part of the point, and although it is the least part of the sun or rather of the solar rays which illumine and warm all the surface of the mirror, this point nevertheless contains within itself the whole sum and power whether of heat or radiance of which all the surface of the mirror is capable. The derived pyramid when equal in bulk is similar in all its powers to the primitive, and when this equality is exceeded it becomes so much weaker in proportion as its size surpasses the bulk of the primitive.

C.A. 347 r. a

EYE

The thing seen through an aperture that is less than the base of the visual pyramid will be seen along a line that goes crosswise, and the thing on the right hand will go to the left eye, and will not be able to be seen by two eyes at one and the same time and if it is seen it will be imperfectly discerned.

C.A. 347 v. a

OF THE EYE AND LIGHT

If you look at a luminous body in the far distance through a small hole it will seem to grow less, and if you look at it near at hand it will not undergo any change. That is that if you look at this light at a distance of one or two braccia from the aforesaid hole it will not undergo any change whether you are looking at it through this hole or outside of it.

C.A. 351 v. b

How and why many things seen in a mirror come to the eye upside down.

Why anything seen in a mirror appears greater than it is.

Why anything looking at itself in a mirror appears less.

What sort of mirror it is which shows the things exactly.

What sort of mirror shows them outside itself.

How the mirror is the master of painters.

Why the eye goes varying hour by hour, enlarging and lessening.

Why the pupil in proportion as it has a greater light in front of it becomes less, and why on the other hand it increases in the dark.

Why the things seen by the eye when continuing are small within the eye and appear large.

Why a thing seen through a chink with both the eyes becomes double and is transposed; that is to say the thing seen on the right hand goes to the left eye, and similarly that on the left hand goes to the right.

Why a building among clouds appears greater.

Why the eye cannot see perfectly except in a straight line.

Why pyramidal lines which start from the eyes come to a point in the thing seen.

Why when the said pyramid proceeds from the eyes and comes to a point in an object that is in water the lines bend as they reach the water and do not keep their straightness.

How the things seen form a pyramid only in the eye.

How the two eyes form a pyramid in the thing seen. C.A. 360 r. c

That eye will preserve within itself more images of the sun which is looked upon a greater number of times by this sun. C.A. 369 r. c

A dark place will seem sown with spots of light and a shining place with dark round spots, when seen by the eye which has recently gazed many times and rapidly at the body of the sun. C.A. 369 v. d

Method of seeing the sun in an eclipse without causing suffering of the eye:

Take a sheet of paper and make holes in it with a knitting-needle and look at the sun through these holes. Tr. 10 a

The eye which finds itself in the centre between the shadows and the lights that surround the shaded bodies, will see in these bodies the greater shadows that are in them meeting themselves within equal angles that is of the visual incidence. Tr. 16 a

Every man always finds himself in the centre of the earth's circumference and below the centre of its hemisphere and above the centre of this earth. Tr. 24 a

The movement of an object near to a stationary object often causes this stationary object to seem to transform itself to the movement of the moving object and the moving object to seem stationary and fixed.

PAINTING

Things in relief seen close at hand with one eye will seem like a perfect picture.

[*Diagram*]

If with the eyes *a b* you observe the point *c*, this point *c* will appear at *d f*.

But if you look at it with one eye only it will seem to you *h* in *m o*, and painting will never of itself have these two varieties. Tr. 69 a

The medium that is between the eye and the object seen transforms this object to its own colour. So the blueness of the atmosphere causes the distant mountains to seem blue; red glass causes anything that the eye sees through it to seem red. The light created by the stars round about them is obscured by the darkness of the night that lies between the eye and the radiance of the star. Tr. 70 a

PERSPECTIVE AND MOVEMENT

Every body that moves rapidly seems to colour its path with the impression of its hue. The truth of this proposition is seen from experience; thus when the lightning moves among dark clouds the speed of its sinuous flight makes its whole course resemble a luminous snake. So in like manner if you wave a lighted brand its whole course will seem a ring of flame. This is because the organ of perception acts more rapidly than the judgment. A 26 v.

Why the movement of water although slower than that of man always seems swifter:

The reason of this is that if you look at the movement of the water your eye will not be able to fix on anything, but its action is as that of things seen in your shadow when you are walking; for if the eye attempt to distinguish the nature of the shadow, the wisps of straw or other things contained in it appear of rapid movement and it seems that these are much more swift to flee from the said shadow than the shadow is to proceed. A 58 v.

If the eye looks at the light of a candle at a distance of four hundred braccia, this light will appear to this eye which looks at it increased a hundred times its true quantity; but if you place a stick in front of it

somewhat larger than this light, this stick which would appear two braccia wide will hide it. This error therefore comes from the eye which takes the luminous images not only with the point of its light but also with the whole of this light, and of this I will define the reason in another place.

c 6 r.

The eye will retain and preserve better within itself the images of luminous things than of shaded things.

The reason is that the eye in itself is completely dark, and since like amid like cannot be distinguished, the night or other dark things can[not] be retained or recognised by the eye. The light is entirely contrary, and the more it is divided the more it tends to destroy and change the customary darkness of the eye and so leaves its image imprinted.

c 7 v.

A rod or cord in rapid oscillation appears to be double.

This occurs when a knife is fastened, and the top of it is forcibly pulled to one side and released, so that it quivers many times. The same thing happens with the cord of a lute when one tests it to see if it is a good one. The double movement takes place because when the movement extends to the extremity of the thing moved it is much swifter at this extremity. But this extremity stops and turns back when its desire has been fulfilled, and as the pause is made first at one and then at the other extremity of the movement, the eye must necessarily take the impression of two images of the same thing moved. But tell me why a false cord of a lute makes, as it quivers, two or three images and sometimes four?

c 15 r.

[*The effect on the eye of sudden light*]

The eye which is used to the darkness is hurt on suddenly beholding the light and therefore closes quickly being unable to endure the light. This is due to the fact that the pupil in order to recognise any object in the darkness to which it has grown accustomed, increases in size, employing all its force to transmit to the receptive part the image of things in shadow. And the light, suddenly penetrating, causes too large a part of the pupil which was in darkness to be hurt by the radiance which bursts in upon it, this being the exact opposite of the darkness to which the eye has already grown accustomed and habituated, and which

seeks to maintain itself there, and will not quit its hold without inflicting injury upon the eye.

One might also say that the pain caused to the eye when in shadow by the sudden light arises from the sudden contraction of the pupil, which does not occur except as the result of the sudden contact and friction of the sensitive parts of the eye. If you would see an instance of this, observe and note carefully the size of the pupil when any one is looking at a dark place, and then cause a candle to be brought before it, and make it rapidly approach the eye, and you will see an instantaneous contraction of the pupil.

C 16 r.

PAINTING

First — The pupil of the eye contracts as the light reflected in it increases.

Second — The pupil of the eye expands as the brightness of day or of any other light reflected in it grows less.

Third — The eye sees and knows objects of vision with greater intensity when the pupil is more dilated; and this is proved in the case of the nocturnal animals such as cats and others, and birds such as the owl and suchlike in which the pupil undergoes a great variation from large to small in the dark and in the light.

Fourth — The eye when placed in an illuminated atmosphere can discern the darkness within the windows of habitations which are themselves in light.

Fifth — All colours when placed in shadow seem to be equally dark.

Sixth — But all colours placed in light keep their essence unchanged.

E 17 v.

If the object interposed between the background and the eye is less than the pupil of the eye no part of the background will be covered by this object.

F 28 v.

The rays of luminous bodies that are remote from the eye will seem of great length, because no object which sends an image is in closer proximity to the pupil of the eye than the object imprinted on the rim of the eye which touches the pupil and from there sends the image to the eye.

The rays of luminous objects will seem shorter when these objects are near to the eye than when they are far away, because, if the lids of

the eyes are half closed as is done by those who wish to see rays round the light, and these lids occupy little space below and above this light, and the rays therefore are not able to open more than whatever may be this space seen by the eye, it is necessary that in this short space one sees short rays, and in a long space long rays as is shown above [*diagram*].

F 29 r.

How the rays that are seen around a luminous body in contracting the eyelids are produced in the eyes and not elsewhere:

Convex mirrors will reflect the rays that they receive from the luminous body in all the parts that see the mirror where the luminous body sees it.

The luminous body sends three images of itself to the eye, of which one goes straight to the pupil; the other two strike upon the convexity of the eyelids and from there leap back in opposite movements to the opposite edges of the eyes, and from the edges they leap back into the eyeball ('luce'), and join themselves below and above to the first image, with the brilliance which has been imprinted on the eyelids in the form of rays; and the luminous body does this when the eye is drawn together as when one takes aim at a target.

This is proved:— let the eye be inclined as has been said and you will see two groups of rays around the luminous separated body, of which one part goes upwards and the other downwards; and if you hold your finger up against the light, putting it crosswise a little below the luminous body, and raise it towards the light with a slow movement until you reach the origin of the light from below, and then observe how instantly this luminous body will lose all its rays above; and if you make a contrary movement crosswise with your finger, commencing above the light, and with slow movement lower your finger until it meets the summit of the light, you will then see that all the rays below are lacking; and this proves our proposition, for if *a* be the luminous body, then *a o* the first ray from its centre goes straight to the pupil of the eye, that below, *a m*, strikes upon the convexity of the eyelids below the eyelashes, and makes several images, and these, as soon as they are formed, are reflected upon the lid *n*, which forms the thick part of the covering of the eye; and from there it leaps back into the eyeball ('luce'), together with all the images formed in the hairs of the eyelids, and these are somewhat long and are separated and proceed with points raised spreading themselves out towards the extremities as do the real eyelashes.

Now to bring our purpose to a conclusion, I call *t s* the part between the commencement of the light and your eye; you will cut the ray *a m*, consequently, because of this the ray will not make its impression on the convexities or curves of the eyelids below, and therefore the ray above will cease at *n* and consequently in the eyeball ('luce'), for if the cause of the images *m* be lacking the effects of the rays *m n* will be lacking. Here then is the explanation of why when the ray is covering the light below, the ray above is lost altogether.

The adversary here says that it seems to him that this image proceeds from the luminous body and passes between the eyelids and imprints itself on the thick part of the edges of the eyelids, and that from there they leap to the pupil, and that this image emits rays because it is divided by the hairs through which it passes.

To this the reply is that in this event whatever might fill the image below the rays above would not fail.

F 30 r. and 29 v.

There is the same proportion one with another between the spaces that there are between the images of the stars upon the surface of the eye and that of the spaces interposed between the stars of the heaven.

Although the images of the stars may be all in all the surface of the eye and all in each of its parts, and each image may be superimposed upon each of the other images as it appears to another eye which regards it after the manner of the surface of a mirror, it remains none the less the fact that from the inner side of the pupil which covers for it the arrival from without of an image of the star, this image will not turn to imprint itself in another part of the eye but will remain without impression in the eye, because the spot to which it directed itself is impeded by the aforesaid interposition.

F 31 v.

The images of opaque bodies do not superimpose themselves one upon another when the eye that scrutinises them is without movement.

In the same mirror or pupil is the image of all the objects placed before it, and each of these objects is all in the whole surface of the mirror and all in each of its smallest parts.

There is an example of this in the movement of the eye; if it sees the moon with all the stars in this mirror, and marks them on its surface, and then the eye moves a little, it will be able to distinguish them so

many times upon this mirror, clearly marked one above the other, and this it will be able to do an infinite number of times.

F 32 r.

The whole pupil of the eye which with each of these circles from the greater to the less goes diminishing an infinite number of times can see the whole body of the star; but it will see it as much smaller as it sees it with a less expansion.

Why in looking at the heaven one sees many stars of great radiance, and in looking at them through a very minute hole made in a sheet of paper placed in contact with the eye you see again the same number of stars but they will be much diminished.

F 32 v.

OF THE FACULTY OF SIGHT

If all the images which come to the eye met in an angle, by the definition of the angle they meet in a mathematical point which is proved to be indivisible; then all things seen in the universe would seem one and that would be indivisible, and there would be no more space from one star to another which would be reckoned in such an angle.

And if experience shows us all things separated with spaces proportioned and definite, this power which imprints the images of objects is also itself divisible into as many larger and smaller parts as there are images of the things seen. We conclude therefore that the sense takes the images which are reflected on the surface of the eye, and then judges them within, and therefore they do not meet in a point nor as a consequence in an angle.

Every surface of a transparent body both within and without is formed fitted to receive the images of its objects.

In no part of transparent bodies enclosed by their surfaces is there lacking the power to receive or create some image, but each is well fitted to afford a passage to the images of the surface.

F 34 r.

That luminous body will show itself of less size at the same distance which loses more of its radiance.

This is shown by an iron rod heated through part of its length when in a dark place; although it is of uniform thickness, it appears to be considerably bigger in the heated part, and the more so as it is more heated. The reason for this follows:—

Every luminous body makes visible rays in the image which it transmits to the eye; and the rays are so much longer as it is of greater brilliance; and so conversely. F 37 r.

Many are the times that the images of one and the same luminous body will be two or three times at the same time in the same eye.

They will be twice there when the eye closes somewhat as it does when it looks at light which is too strong and when the head is somewhat bending as in the figure *a*, in this case it makes two rays; one strikes against the humid circumference of the lower eyelid and then leaps back to the pupil, and the other ray goes straight to this pupil; it will recur three times as in the figure *b*, one on the eyelid above, one on that below and one in the centre of the pupil. And the aforesaid two or three images of the light arriving at the same sense appear one single image, but greater than corresponds to the image of the same body which transmits to the two eyes two images, and the sense takes them for one single image. F 36 v. and 37 r.

As regards the pupil of the eyes of all animals both those of the land and those of the water, nature has so ordained that when they are affected by greater or less brightness the pupil that is the black portion of the eye contracts or expands. This happens because as the excess of brightness causes a change in the eye the eye or pupil closes up after the manner of a purse, consequently the great brightness becomes small in size and in splendour in proportion to its contraction or diminution. When these pup ls are in darkness they become large and the brightness is diminished; in this way it comes about that they increase according to the increase of this brightness, and so the quantity of the objects seen by such a pupil is increased.

And this supplies a reason why when the light of a candle is removed farther away from the eye, this light having thereby its brightness diminished the pupil increases and it causes the figure of the light to increase. F 39 v.

The image of the sun imprinted on the surface of the water creates rays which shine over a great distance both within and outside the water as though it was a real light.

Why when the image of the light of the candle diminishes upon the

eyeball when this candle is removed to a great distance from this eye it does not diminish in the judgment of the spectators except in degree of radiance.
F 40 r.

The eye contracts and diminishes the pupil to such an extent in looking at luminous things that when afterwards looking at things of less radiance they appear shaded.

If the eye which has been in a shaded place should then see objects of only a moderate degree of brightness they will appear extremely bright.

And the reason of this is that the pupil increases so much while in the dark places that it afterwards sees objects of a moderate degree of brightness incorrectly.
F 50 r.

In every spot in which the sun sees the water the water also sees the sun, and in each of its parts it can present the sun's image to the eye.
F 61 v.

If you bring your eye as near as you can to the surface of the sea you will see the image of the sun in a wave of the water, and you will be able to measure it and you will find that it is very small.

If you bring your eye near the surface of the water of the sea or of a pool which is between your eye and the sun you will find that the image of the sun on this surface shows itself very small. But if you retire a distance of several miles from this sea you will perceive a proportionate increase in the image of the sun; and if the first image preserves the true shape and radiance of the sun as do mirrors, the second does not keep either the shape or the radiance of the sun but is a figure with broken contour lines and a lesser degree of radiance.

The figure of the image with contour lines broken and confused is formed by the blending of many images of the sun reflected to your eye by many waves of the sea, and the lesser degree of radiance springs from the fact that the shadowed and luminous images of the waves come to the eye all mingled together and consequently their light is affected by their shadows.

This however cannot happen with the surface of a single wave when you have approached very near to it with your eye.
F 63 v.

The image of the sun in the convex mirror increases as it recedes from this mirror and the solar body disappears as it recedes.
F 76 r.

Show first how every light remote from the eye makes rays which appear to increase the figure of this luminous body; and from this it follows that . . .

The eye does not diminish its light at any distance, because the image of the light which imprints itself on the surface of the eye illuminates within as do the windows of paper, which diffuse the light taken by them through those places which see this paper, and which at first could not see the cause of the illumination of this paper when the paper was not there. The sun also on being reflected in the mirrors causes the image without passing within to be reflected outwardly as though it were a real light; and if the lead were not behind this glass of the mirror, the image of the sun which imprints itself on the surface of the glass would pass within and cast its light within or behind this mirror. And thus does the eye which receives within the light of this image and spreads it considerably in the visual faculty.

F 94 V.

[*Distant lights and reflection*]

Why as the image of the light of the candle diminishes when it is removed to a great distance from the eye the size of this light does not diminish but it lacks only the power and brightness of its radiance.

A light that is less in quantity is less also in illuminating power, but in that it does not change its position it does not lose its first quantity of radiance in all the places where it formerly shone. This is proved: the light of the sun given to the surface of the water is reflected back and emits rays as though it were a material light both within and without, and actually illuminates the objects set over against it and also those within.

F 95 r.

[*Presbyopia*]

Why when men are somewhat advanced in years they see better at a distance.

Sight is better at a distance than near at hand with men who are somewhat advanced in years because the same thing transmits a smaller impression of itself to the eye when it is remote than when it is near.

G 90 r.

Things near to the eye will seem of greater bulk than those remote.

Things seen with both eyes will seem rounder than those seen with one eye.

Things seen between light and shadow will appear to have the highest relief.

H 49 [1] r.

[*Man and owl*]

All things seen will appear larger at midnight than at midday and larger in the morning than at midday.

This takes place because the pupil of the eye is considerably smaller at midday than at any other time.

To just such extent as the eye or pupil of the owl is greater in proportion to the creature than is that of man it sees more light at night than man does; as a consequence at midday it sees nothing unless its pupil grows smaller and in the same way at night it sees things larger than by day.

H 86 [38] r.

The larger the pupil the larger will be the appearance of the objects it sees.

This is evident when we look at luminous and especially at heavenly bodies. When the eye emerges from the darkness and suddenly looks at these bodies they will appear larger at first and will then diminish. And if you look at these bodies through a small hole you will see them smaller because a smaller part of the pupil is functioning in this act.

H 88 [40] r.

When the eye emerging from darkness suddenly sees a luminous body it will appear much larger at the first glance than as it goes on looking at it.

A luminous body will seem larger and more luminous when seen with both eyes than when seen with one.

This luminous body will appear of less size when it is seen by the eye through a smaller hole.

The luminous body of elongated shape will show itself rounder in form when it is situated at a greater distance from the eye.

H 91 [43] v.

When at night the eye finds itself between the light and the eye of a cat it will see this eye looking like fire.

H 109 [34 v.] r.

Objects seen by the same eye will sometimes appear large and sometimes small.

H 133 [10 r.] v.

Example of the enlargement and contraction of the pupil through the movement of the sun or other luminous body:

The darker the sky the greater the stars will seem, and if you light up the atmosphere these stars will show themselves less. And this change proceeds only from the pupil which expands and contracts according to the clearness of the atmosphere which finds itself between the eye and the luminous body. Let the experiment be made with a candle placed above the head while you are looking at this star; afterwards proceed to lower this candle, little by little, until it is near the ray that comes from the star to the eye, and you will then see the star diminish so much that you will almost lose sight of it. I 19 v.

The pupil of the eye in the open air varies its size with every degree of the sun's movement. And as it varies its size the same object when seen by it will appear of different sizes, although it often happens that the comparison with surrounding things does not allow this change to be discerned when you look at a particular object. I 20 r.

No opaque body of spherical shape seen by two eyes will ever show itself of perfect roundness.

[*Diagram*]

a is the position of your right eye; *b* is the position of the left. If you close the right eye you will see your spherical body around the centre *b*, and if you close the left eye, then the said body will surround the centre *a*.[1] I 43 r.

The more nearly an object approaches to the eye the more it shows itself at a greater angle; and the image of this thing does the opposite, seeing that in proportion as it is found by measurement to be nearer to the eye it shows itself less in shape. I 49 [1] v.

[*Eyeball of glass*]

In order to see what function the eyeball ('luce')[2] serves in the pupil cause a thing resembling the eyeball to be made out of glass. K 118 [38] v.

[1] MS. has *b*.

[2] A note in M. Ravaisson-Mollien's edition of the Paris Manuscripts is as follows: 'Le mot "luce" est souvent pris pour prunelle, mais signifie proprement (voir la page suivante) (118 [38] r.) toute la partie de l'œil qui luit, la prunelle avec l'iris.'

[The structure and anatomy of the eye]

The pupil of the eye is situated in the centre in the eyeball ('luce') which is of the shape of part of a sphere which takes the pupil at the centre of its base. This 'luce' forming part of a sphere takes all the images of the objects and transmits them by the pupil within to the place where the vision is formed.

In the anatomy of the eye, in order to be able to see the inside well without spilling its watery humour, you should place the complete eye in white of egg and make it boil and become solid, cutting the egg and the eye transversely so that no part of the middle portion may be poured out.

K 119 [39] r.

[Optical illusions. A brand of fire]

There is as much to move the eye when the luminous object remains fixed as there is to move this object when the eye remains fixed.

What is said in the first part is proved by the past, and I will prove the second part by the help of this same past.

For if when the eye is fixed you draw a brand of fire in a circle or from below the eye upward this brand will seem to be a line of fire which rises upwards from below, and yet this brand cannot actually be in more than one part of this line at one time.

And in the same way if this brand remain fixed and the eye move downward from above it will appear to this eye that the brand is rising up from below in a continuous line.

K 119 [39] v.

[Optical illusions. Brands of fire. Stars]

If the eye that looks at the star turns swiftly in an opposite direction, it will appear to it that this star forms itself into a curving line of fire. *[Diagram]*

Let *a b c* be the eyeball ('luce') of the eye which looks at the star *d*; I maintain that if the eyeball moves the part *a* rapidly to *c* then *b* in coming to the place *a* will take the appearance of a continuous line of the colour of the star. And this occurs because the eye preserves for a certain space of time the image of the thing that shines, and because this impression of the radiance of the star is more enduring in the pupil than was the time of its movement, this impression continues together with the movement in all the positions which pass opposite to the star.

K 120 [40] r.

When the eye changes its position which has been fixed in relation to a near object it will seem to it that distant objects are very rapid and that the first is without movement and that the star moves by the line of the eye.

[*Diagram*]

Let us say that the eye *a* has fixed its range of vision upon the object *c* and that while having its vision fixed upon *c* it itself moves actually from *a* to *b*; the star *d* when seen by the lines of the eye other than the central ones will appear to it very swift, and in the time during which the eye goes from *a* to *b*, the star will appear to it to have moved the whole part of the sky *d e*.

K 122 [42] v.

But if the eye which changes its position keeps its vision fixed upon the star it will seem to it that all the objects seen on the lines that are not central are fleeting and vanish away in movement contrary to that of the eye.

[*Diagram*]

Let us say that the eye *b* having its vision fixed upon the star *d e* itself moves actually from *b* to *a*; it will then appear to the eye that as its lines which are not central have exchanged so many times the images of the object *c* it will be moved in a direction contrary to that of the eye from *n* to *c*.

K 122 [42] r.

In proportion as a thing that descends shall descend from a higher position it will appear at the beginning of its movement to be obliged to descend nearer to the eye that sees it than does a thing that descends from a low position.

[*Diagram*]

This which has been said springs from the background of the movable thing, which is the sky where this movable thing shows up prominently, and the lower the movable thing upon this background the more does the eye see it on a more distant background; as if the eye *p* sees the movable thing at *e* and sees it occupy the part of the sky *d* which seems almost above it; and if it sees the movable thing below at *h* this eye sees it occupy the part of the sky *a*, and in proportion as the distance is from *a* to *d* so to the eye *p* it seems that it has it more at the zenith when at *e* than at *h*, that is that when falling from *d* it seems to it that it ought to fall nearer than when falling from *a*.

K 123 [43] r. and 122 [42] v.

If the proportion of the movement of two movable things is the same as that of their distance from the eye in the same direction the movements of these movable things will always appear equal although they may be of almost infinite diversity.

If half the diameter of the base of a pyramid measures three-quarters of its hypotenuse nothing can remain stable upon the said hypotenuse; but if this should be longer it will support anything.

K. 123 [43] v.

Among the things of equal movement that will appear swifter which is nearer, and the thing will seem slower which is more remote.

[*Diagram*]

Because everything that moves is seen on the field where it ends, and the distant thing in like movement to that of the near thing will occupy less of the field than this near thing in the same time, for which cause occupying a greater space of field it appears so much swifter as the field that it has covered is greater.

K 124 [44] r.

[*Spherical bodies*]

If the spherical body is equal to the pupil that sees it even though it may be at infinite varieties of distances, provided that it can be defined and that the eye is able to discern it it will never be seen as more or less than half. And this happens because its diameter with its extremities always terminates within equal angles between parallel visual lines.

But if the pupil be less than the spherical body situated in front of it it will never at any variety of distance be able to see the half; and it will see as much less in proportion as it is nearer to it, and as much more as it is more remote.

K 124 [44] v.

An object less than the pupil placed before the eye will not cover up any distant object for this pupil.

No spherical body less than the pupil will ever be seen by a single pupil without it seeing more than half of it although it be at whatever distance it may wish. And it will see so much more of it as the medium is nearer and so much less as it is more remote from the eye that sees it.

K 125 [45] r.

[*Movements*]

In the cases of the movement of the thing between the eye and the perforation of the paper you have to make the perforations with very

small holes and to pull the thing which moves as thin as a wisp of straw, and in the movement to touch yourself with it on the eyelashes, the paper in front to be a quarter of a braccio distant from the eye and the air to be visible through the openings. Furthermore if you approach nearer to the paper so that the eyelashes almost touch, and move the face at *d* to right and left, with a short movement, you will see that the hairs appear to be moving beyond this hole in a contrary direction to the movement made by your eye. But if the movement of the object is beyond the perforated paper the eye will then see the true movement of the object.

K 125 [45] v. and 126 [46] r.

[*Contrary movements seen at the same time*]

Again it is possible for the same pupil to see the same object at the same time make two opposite movements without the pupil changing. [*Diagram*]

That which is set forth above is seen by the pupil when it sees through a small hole made in the paper by the point of a needle, and keeping the eye close to it and interposing between the eye and the hole a very fine straw, which as you move it from right to left your eye will see in its true movement between the hole and it, in the true position in which this straw actually finds itself moving; and beyond this hole it will see it moving in the opposite direction to its true movement; so that at one and the same time it sees the true and the false movements separately the one from the other.

K 127 [47] r.

[*Visual faculty*]

And the reason of this is that as every vision transmits itself by a straight line if the medium be uniform, the part *a* of the pupil sees *o* beyond the hole at *s*, and it would be impossible to see it through this hole at *q* through *a b q*, that is by a line that is not straight. Suppose now that *o* is lowered to *n*; *p* will see *o* at *r*, and if *o* is lowered as far as *m* then *o* will appear to the lower part of the eye *c* to be raised to the extremity *q*.

The pupil which sees beyond the hole something smaller than itself and near to it, will see with the right part of the pupil the left part of the object, and with the left part it will see the right part of this object; and with the centre of the pupil it will see the centre of the surface of the object, given that it is visible and that the centre of the pupil has in itself visual faculty.

K 126 [46] v.

PUPIL SEEING AN OBJECT TWICE

It is possible for the same pupil to see the same object twice, in two places at the same time.

[*Diagram*]

The lower part *b* of the pupil *a b* sees the object *c* cover *d*, and the upper part *a* of the same pupil sees the same object *c* cover the wall *g f*, beyond the hole *e*, in the position *g*.

Therefore the object *c* is seen at the same time at *d* and *g*, and it is this that I wished to demonstrate.

K 127 [47] V.

As the light diminishes so the pupil of the eye that beholds this light expands. Therefore the eye which looks through a pea-shooter has a larger pupil than the other, and sees the object larger and clearer than the other eye does. You may make a proof of this if you look with both eyes at a white line against a black background, one looking at it through a pea-shooter and the other through the luminous air.

L 13 V. and 14 R.

When the eye in the luminous air is looking at a place that is in shadow this space will seem of much greater darkness than it is.

This happens simply because the eye which is in the air diminishes its pupil the more as the air which reflects it is more luminous; and as the pupil becomes more contracted so the thing seen by it shows itself less luminous.

But when the eye enters into any shaded spot immediately the obscurity of this shaded spot will appear to diminish.

This takes place because in proportion as the pupil enters into the more shaded air so its outline increases and this increase causes the great darkness to seem to diminish.

L 41 V.

Of concave mirrors of equal diameter, that which is of less concavity will unite a greater sum of rays in the percussion of the concourse of these rays, and as a consequence it will kindle a fire with greater rapidity and force.

B.M. 86 V.

It is impossible for the reflection of anything upon the water to be similar in shape to the object which is reflected, in view of the fact that the centre of the eye is above the surface of the water.

B.M. 93 V.

If the seat of judgment of the eye lies within it the direct lines of the images are broken at its surface because they pass from the thin to the dense.

If you stand under water and look at something within the air you will see this thing out of its position, and it will be the same with a thing within the water seen from the air.

B.M. 220 r.

The concourse of the lines created by the images of the objects placed before the eye does not meet in the point within this eye by straight lines.

B.M. 221 v.

Here let us treat of actual movements because as regards spiritual movements there has been some treatment by others.

Actual movement made with swift impetus will never conceal from the eye the object which is behind the body that is moving, if only it be near to the eye and not too much greater than this eye. As would be the movement of certain instruments worked by women, made for convenience of gathering their threads together, which are called 'winders' ('arcolai') among the Florentines and by the Lombards 'turrets' ('bicocche'). For these in their revolving movement are so swift that through being perforated they do not obstruct to the eye anything behind them.

Forster II 101 r.

[*Central line and other lines of eye*]

The eye has one central line and all the things that come to the eye along this line are seen distinctly.

Round about this line are an infinite number of other lines that adhere to this centre line and these have so much less strength in proportion as they are more remote from the central line.

Quaderni IV 12 r.

[*Phenomenon of sun shining on rain-drops*]

And the drop that falls in rain as seen by the eye seems illuminated by the sun, and in its course it seems continuous over so great a space as it shows all the colours of the rainbow, and this it makes greater or less according to the distance.

[*Brand moved in circle seems an unbroken circle*]

The firebrand whirled in a circle passes through an infinite number of adjacent lines and therefore this circle appears united in the air.

Quaderni IV 12 v.

Necessity has provided that all the images of bodies set over against the eye intersect in two places, of which the one intersection is formed within in the pupil the other within in the crystalline sphere; and if this were not the case the eye would not be able to see so great a number of things as it does. This is proved because all the lines that intersect form this intersection at a point, since of bodies nothing is visible except their surfaces, the edges of which are lines by the converse of the definition of the surface, and every smallest part of the line is equal to a point, because smallest is said of that thing than which nothing else can be smaller, and this definition is like that of the point. It is possible therefore for the whole circumference of a circle to transmit its image to its intersection as is shown in the fourth [section] of this [treatise] which says: — all the smallest parts of the images penetrate one another without occupation one of another. These demonstrations are as an example of the eye: — no image of however small a body enters within the eye without being turned upside down, and as it penetrates the crystalline sphere it is turned again upside down, and so the image within the eye becomes upright as was the object outside the eye.

Windsor: Drawings 19150 v.

How every great mass sends forth its images which have the capacity of diminishing to infinity:

The images of every great mass which is divisible to infinity may be diminished to infinity.

Windsor: Drawings 19151 r.

OF THE CENTRAL LINE OF THE EYE

There is only one line of the images that penetrate to the visual faculty that has no intersection, and this has no sensible dimensions because it is a mathematical line and has its origin in a mathematical point which has no dimensions.

Necessity requires according to my opponent that the central line of all the images which enter through the fine and narrow openings into a dark place shall be turned upside down together with all the images of the bodies that surround it.

OF THE INTERSECTION OF THE IMAGES IN THE PUPIL OF THE EYE

The intersections of the images at the entrance of the pupil do not mingle one in another in that space where this intersection unites them;

and this is evident because if the rays of the sun pass through two panes of glass in contact one with another, the one of these being blue and the other yellow, the ray that penetrates them does not assume the hue of blue or yellow but of a most beautiful green. And the same process would occur with the eye if the images yellow and green in colour should come to mingle one with the other at the intersection which they make within themselves at the entrance of the pupil, but as this does not happen such a mingling does not exist.

OF THE NATURE OF THE RAYS FORMED BY THE IMAGES OF BODIES AND THEIR INTERSECTION

The straight line of the rays which transmit through the air the form and colour of the bodies whence they proceed does not itself tinge the air nor can they tinge one another at the contact of their intersection, but they only colour the place where they lose their existence, because this place sees and is seen by the original source of these rays, and no other object that surrounds this original source can be seen from the place where this ray is cut off and destroyed, leaving there the spoil it has carried off. This is proved by the fourth, on the colour of bodies, which says the surface of every opaque body shares in the colour of surrounding objects; so we conclude that the place which by means of the ray that carries the image sees and is seen by the source of this image is tinged by the colour of this object.

How innumerable rays from innumerable images can converge in a point:

As in a point all lines pass without occupation the one of the other through their being without body, so may pass all the images of the surfaces, and as each given point faces every object opposite to it and every object faces the opposite natural point, also through this point may pass the converging rays of these images which after passing it will reform and increase again to the size of these images. But their impressions will appear reversed as is shown in the first above, where it is said that every image intersects at the entrance of the narrow openings made in an extremely thin substance.

In proportion as the opening is smaller than the shaded body by so much the less will the images transmitted through this opening penetrate one into another. The images which pass through the openings in a

dark place intersect at a point so much nearer the opening as this opening is of less width. . . .

It is impossible that the images of bodies should be seen between the bodies and the openings through which the images of these bodies penetrate; and this is evident because where the atmosphere is illuminated these images do not become visible.

When images are duplicated by mutually penetrating one another they always have double depth of tone.

Windsor: Drawings 19152 r. and v.

Describe how no object is itself defined in the mirror but is defined by the eye which sees it within the mirror, for if you look at your face in the mirror the part resembles the whole, seeing that the part is all in the whole of the mirror and it is all in every part of the same mirror, and the same happens with the whole image of every object placed opposite to this mirror.

Windsor MSS. R 209

X

Acoustics

'If you cause your ship to stop, and place the head of a long tube in the water, and place the other extremity to your ear, you will hear ships at a great distance from you.'

[*Acoustics*]

Of the sounds that may be made in the waters as yonder from the ditch at Sant' Angelo.

C.A. 65 r. a

THE NOTE OF THE ECHO

The note of the echo is either continuous or intermittent, it occurs singly or is united, is of brief or long duration, finite or endless in sound, immediate or far away.

It is continuous when the surface on which the echo is produced is uniformly concave. The note of the echo is intermittent when the place which produces it is broken and interrupted. It is single when it is produced in one place only. It is united when it is produced in several places. It is either brief or long-continuing, as when it goes winding round within a bell which has been struck, or in a cistern or other hollow space, or in clouds wherein the note recurs at fixed distances in regular intervals of time, ever uniformly growing fainter, and is like the wave that spreads itself out in a circle over the sea.

The sound often seems to proceed from the direction of the echo, and not from the place where the real sound is; and similarly it happened at Ghiera d'Adda, when a fire which broke out there caused in the air twelve lurid reflections upon twelve clouds, and the cause was not perceived.

C.A. 77 v. b

Whether the whole circle made in the air by the sound of a man's voice carries with it all the word spoken, since the part of this circle having struck upon another man's ear does not leave the part of this speech in this ear but the whole:

What has been said is shown in the case of light, and you would be able to say whether the whole of the light illumines the whole of a building, since the part of this building would not be illumined merely by a part of this light.

If you wish to dispute the point and say that this light illumines the said part of the habitation not with the whole but with its part, I will give you the instance of one or two mirrors set in different positions on this

spot, each part of this mirror will have within itself the whole of the said light; this shows therefore that this light is all in all and all in every part of this habitation; and it is the same with the voice in its circle.

C.A. 199 v. b

[*Diagram*]

In these two rules, that is of the blow and of the force one may employ the proportions which Pictagoras made use of in his music.[1]

C.A. 267 r. a

OF THE SOUND WHICH SEEMS TO REMAIN IN THE BELL AFTER THE STROKE

'That sound which remains or seems to remain in the bell after it has received the stroke is not in the bell itself but in the ear of the listener, and the ear retains within itself the image of the stroke of the bell which it has heard, and only loses it by slow degrees, like that which the impression of the sun creates in the eye, which only by slow degrees becomes lost and is no longer seen.'

A proof to the contrary

If the aforesaid proposition were true, you would not be able to cause the sound of the bell to cease abruptly by touching it with the palm of the hand, especially at the beginning of its strength, for surely if it were touched it would not happen that as you touched the bell with the hand the ear would simultaneously withhold the sound; whereas we see that if after the stroke has taken place the hand is placed upon the thing which is struck the sound suddenly ceases.

C.A. 332 v. a

[*Ventriloquism*]

The ear is deceived by the perspective of the voice which seems to send itself to a distance and does not change its position.

C.A. 357 v. b

If a man jumps on the points of his feet his weight does not make any sound.

Tr. 5 a

I ask whether a slight sound close at hand can seem as loud as a big sound afar off.

Tr. 12 a

[1] The reference is presumably to Pythagoras's discovery of the dependence of the musical intervals on certain arithmetical ratios.

THE NATURE OF THE EFFECT OF THE ROAR OF THE CANNON

The rumbling of the cannon is caused by the impetuous fury of the flame beaten back by the resisting air, and that quantity of the powder causes this effect because it finds itself ignited within the body of the cannon; and not perceiving itself in a place that has capacity for it to increase, nature guides it to search with fury a place suitable for its increase, and breaking or driving before it the weaker obstacle it wins its way into the spacious air; and this not being capable of escaping with the speed with which it is attacked, because the fire is more volatile than the air, it follows that as the air is not equally volatile with the fire it cannot make way for it with that velocity and swiftness with which the fire assails it, and therefore it happens that there is resistance, and the resistance is the cause of a great roar and rumbling of the cannon.

But if the cannon were to be moved against the oncoming of an impetuous wind it would be the occasion of a greater roar made by reason of the greater resistance of the air against the flame, and so it would make a less rumbling when moved in the line of the wind because there would then be less resistance.

In marshy places or other wide tracts of air the cannon will make a louder report close at hand, and at a lesser distance it will be perceived that up on the mountains or in other places where the air is rarefied, if the air be thick or thin equally and without direct movement of winds, the roar will be equally perceptible round about its cause, and it would go on expanding from circle to circle just as the circles of water do when caused by a stone thrown into it; and in that place where similar instrumenti are being used the adjacent air will break or scatter all the things of weak power of resistance. All the large vessels with wide mouths will become broken, the windows of paper and such like things; the neighbouring roofs will all be shaken on their supports; and this will take place though many windows and doors stand open, and walls which are thin and without buttresses will become dangerous.

This happens because the air swells and presses itself out and wishes to escape in all directions in which movement is possible. Doors windows trees and such things as these will all be moved, and if you set an arrow lightly fastened with a small stone it will be carried about a distance of six miles through the movement of the air.

Tr. 44 a

WHAT THING IS SOUND CAUSED BY THE BLOW?

The time in which the blow is produced is the shortest thing that can be done by man, and no body is so great but that being suspended it makes an instant movement at a sudden blow; which movement beats back in the air and the air sounds as it touches the thing moved.

WHETHER THE SOUND LIES IN THE HAMMER OR IN THE ANVIL

I say that because the anvil is not suspended it cannot resound. The hammer resounds in the jump that it makes after the blow, and if the anvil were to re-echo the sound made on it by every small hammer as does the bell with every different thing which strikes it with the same depth of tone, so would the anvil when struck by each different hammer; and as therefore you hear different notes with hammers of different sizes it follows that the note is in the hammer and not in the anvil.

Why the thing which is not suspended does not sound and when suspended every slight contact takes away the sound from it:

The bell when struck makes a sudden tremor and the sudden tremor causes it instantly to strike the circumscribing air, which instantly resounds.

On being impeded by any slight contact it does not make the tremor or strike and so the air does not resound.

If the bird suddenly beats the air ought this to resound or no:

I maintain it does not because as the air penetrates through the thing that beats it it does not receive the blow and consequently it cannot make sound.

OF THE BOMBARD OR ARROW

Here sounds movement of air more powerful than the resisting air.

Tr. 64 a

CONCERNING VIOLENCE

I say that every body moved or struck keeps in itself for a time the nature of this blow or movement, and keeps it so much more or less in proportion as the power of the force of this blow or movement is greater or less.

Example

Observe a blow given on a bell how much it preserves in itself the noise of the percussion.

Observe a stone projected from a bombard how much it preserves the nature of the movement.

The blow given on a thick body will keep its sound longer than on a thin body, and that will be of longest duration which is made upon a body that is suspended and thin. The eye keeps within itself the images of luminous bodies for a certain interval of time.

Tr. 73 a

It is possible to recognise by the ear the distance of a clap of thunder, on first seeing its flash, from its resemblance to the note of the echo.

The voice is all in all and all in the part of the wall surface where it strikes. And that part which is formed in such a way as to be fitted to send back the percussion, gives back the voice in as many different small portions of itself as there are different positions of the hearers.

The ear receives the images of sounds by straight curved and broken lines and no twists can break its function.

A 19 r.

The voice after it has struck on the object will return to the ear by a line at a slant equal to that of the line of the incidence; that is the line which carries the voice from its cause to the place where this voice can reform itself; and this voice acts in the manner of a thing seen in a mirror which is all in all the mirror and all in the part of it. Let us say therefore that the mirror is *a b* and the thing seen is *c*; just as *c* sees all the parts of the mirror so all the parts of the mirror see *c*; therefore *c* is all in all the mirror because it is in all its parts; and it is all in the parts because it sees itself in as many different parts as there are different positions of spectators . . .

Let us take the sun as an example: if you should walk along the bank of a river and watch the sun's reflection in it, for so long a time as you walk along the bank of the river it will seem that the sun moves with you, and this because the sun is all in the whole and all in the part.

A 19 v.

OF A BLOW

The blow given in the bell leaves its likeness behind it impressed as is that of the sun in the eye or the scent in the air; but we wish to discern whether the likeness of the blow remains in the bell or in the air, and this

is ascertained by placing your ear to the surface of the bell after the blow.

The blow given in the bell will cause a slight sound and movement in another bell similar to itself, and the chord of a lute as it sounds produces movement and response in another similar chord of like tone in another lute, and this you will perceive by placing a straw upon the chord similar to that which has sounded.

A 22 V.

OF THE VOICE

Whether many tiny voices joined together will make as much sound as one large one. I maintain they will not; for if you were to take ten thousand voices of flies all together they would not carry as far as the voice of a man, and if such voice of a man were split up into ten thousand parts no one of these parts would be equal to the size of the voice of a fly.

A 23 r.

OF SOUND

Whether a sound that is double another will be heard twice as far. I maintain that it will not for if it were so two men shouting would be heard twice as far as one; but experience does not confirm this. A 43 r.

If you cause your ship to stop, and place the head of a long tube in the water, and place the other extremity to your ear, you will hear ships at a great distance from you.

You can also do the same by placing the head of the tube upon the ground, and you will then hear anyone passing at a distance from you.

B 6 r.

[*Of the echo*]

The voice after having proceeded from the man and having been beaten back by the wall will fly upwards. If there be a ledge above this wall with a right angle the surface above will send back the voice towards its cause.

How one should make the voice of the echo which whatever thing you may say will be repeated to you in many voices:

[*Drawing*]

Braccia one hundred and fifty from one wall to the other.

The voice which issues forth from the horn forms itself on the opposite wall and from there leaps back to the second, and from the second [it returns] to the first, as a ball that rebounds between two walls which diminishes its bounds; and so the voices grow less. B 90 v.

OF THE SOUND MADE BY PERCUSSION

Sound cannot be heard at such close proximity to the ear that the eye does not first see the contact of the blow, and the reason is this: — if we admit that the time of the blow is indivisible, that the nature of the blow does not produce its expansion upon the body which has been struck without time, that no body struck can resound whilst the thing that strikes is touching it, and that the sound cannot travel from the body struck to the ear without time, then you must admit that the thing which strikes is separated and divided from the thing struck before this thing struck can of itself have any resonance; and not having this it cannot give it to the ear.

c 6 v.

OF REFLEX MOVEMENTS

I wish to define why bodily and spiritual movements after the percussion made by them upon the object spring back within equal angles.

OF BODILY MOVEMENTS

I say that the note of the echo is cast back to the ear after it has struck, just as the images of objects strike the mirror and are thence reflected to the eye. And in the same way as these images fall from the object to the mirror and from the mirror to the eye at equal angles, so the note of the echo will strike and rebound within the hollow where it has first struck, at equal angles to the ear.

c 16 r.

OF SOUNDS

Why the swift wind which passes through a reed makes a shrill sound:

The wind passing through the same reed will make a sound so much deeper or shriller in proportion as it is slower or swifter. And this is seen in the changes in the sounds made by trumpets or horns without holes and also in the winds that howl in the chinks of doors or windows. This originates in the air, where the sound having issued forth from the instrument traverses the valley and proceeds to spread itself in a greater or less degree according as the air is driven by a greater or smaller force. This may be proved.

E 4 v.

Why the reflex movement of the stone makes more noise in the air than its incidental movement, the reflex movement being less powerful

than the incidental, and whether this reflex movement makes a greater or less sound as the angle of its incidence is more or less obtuse. But as regards the first question the reflex movement is made by the composite movement of this projectile, and the incidental movement is made by the same movement of the same projectile; and for this reason the sound is in the reflex movement of the projectile and not in the incidental movement. As regards the second question in proportion as the angle is more obtuse the projectile is more disposed to revolve than when the percussion is made between acute angles.

E 28 V.

[*Acoustics*]

The sound caused by the wind or by a blow will grow fainter when as a result of time or distance it is further removed from its cause.

The stroke given to the bell will go on growing less as more time passes and it is the same whether the distance is far or near.

H 72 [24] V.

[*Of separated forces: — rivers, bells, ropes*]

Of dividing the force of rivers:

If the excessive size of the rivers damages and destroys the sea coasts, then if such rivers cannot be diverted to other places they should be parted into small streams.

Comparison

If a bell which sounds is heard at six miles and weighs six thousand pounds, six miles being eighteen thousand braccia . . . But not to extend myself in too many arguments I maintain that if I were to split it up into tiny bells it will not be heard at an eighth of a mile even though all the metal rings in the bells at the same time.

Similarly if a rope supports a hundred thousand ounces and you separate it into a hundred thousand strands, each strand of itself will not support one eighth part of an ounce. And so it follows with all the separated powers.

I 111 [63] r.

SOUND OF THE ECHO

If the sound of the echo answers in two divisions of time at thirty braccia, in how many divisions will it answer if it is a hundred braccia away?

If the sound of the echo answers me in two divisions of time at a

distance of thirty braccia, with two degrees of power in its noise, with how many degrees of noise will it reveal itself to me at a distance of a hundred braccia?

I 129 [81] v.

[*Sound — laws of*]

Why will the deep-toned vessel with contracted mouth have a much deeper and lower sound in its percussion when it has a narrow mouth than when it is wide?

L 63 r.

How the sound of the voice is lost by reason of distance:

[*With diagram*]

At the distance *a b* the two voices *m n* are diminished by half; consequently although there are two half voices they are not as powerful as one whole voice but merely as a half.

And if an infinite number of halves should find themselves at such distance they would only amount to a half.

And at the same distance the voice *f* which is double *n* and *m* having lost the fourth part of its power remains consequently as a voice and a half, and surpasses in three times the power, so that at three times the distance, that is at *g*, *f* will be as powerful as *m n* are at the distance *a b.*

L 79 v.

[*Voice in distance*]

Where one voice does not carry, a multiple however great made up of voices equal to the aforesaid will not carry.

L 80 r.

[*Noise of the mortar*]

[*With drawing*]

One proves by this example how the noise made by the mortar (bombarda) is nothing but a separation of compressed air.

L 89 v.

[*Sound of bombards — how produced*]

The wave of the flame created by the setting fire to the powder of the bombards is that which striking the air opposite to it creates the sound.

M 82 r.

If flies made with their mouths the sound that is heard when they fly then since it is very long and sustained they would need a great pair of bellows for lungs in order to drive out so great and so long a wind, and

then there would be a long silence in order to draw into themselves an equal volume of air; therefore where there was a long duration of sound there would be a long intermission. B.M. 257 v.

If a bell were to be heard with its sound two miles, and then it were to be melted down and cast again into a number of small bells, certainly if they are all sounded at one time they will never be heard at as great a distance as when they were all in one bell. Forster II 32 v.

If you make two bells of the same shape and the one double the size of the other but of the same weight the larger will have twice the depth of tone. Forster III 5 r.

[*Of the buzzing of flies*]

That the sound which flies make proceeds from their wings you will see by cutting them a little, or better still by smearing them a little with honey in such a way as not entirely to prevent them from flying, and you will see that the sound made by the movement of the wings will become hoarse and the note will change from high to deep to just the same degree as it has lost the free use of its wings. Fogli A 15 v.

XI

Astronomy

'The moon has every month a winter and a summer. And it has greater colds and greater heats and its equinoxes are colder than ours.'

Make glasses in order to see the moon large. C.A. 190 r. a

If you know the distance of a body you will know the size of the visual pyramid if you take a section of it near the eye upon a wall and then remove the line so far from the eye as to double the size of the section. Then note the distance from the first to the second section and ask yourself: — if within such a space the diameter of the moon increases for me so much above the first section what will it do in the whole space that is between the eye and the moon? It will form the exact diameter of this moon.

[*Diagram*]

Measure of the size of the sun, knowing the distance. C.A 243 r. b

If the water of the moon had its centre of gravity at the centre of the earth, it would strip the moon and fall upon us . . . suspended from the centre of its sphere.

If you should be moving towards the sun along that line of water which lies between this sun and its image, you will be sailing along a continuous image which will be of the length of your movement.

Why the moon when surrounded by the luminous part of the sun in the west has greater radiance in the centre of this circle than when there is an eclipse of the sun. This comes about because as it eclipses the sun it casts a shadow upon our ocean, and this does not occur when it is in the west, for then the sun lights up this ocean.

Why in the eclipse of the sun the body of the moon when it is opposite to us shows itself in the middle of the sun with part of its radiance somewhat like that of molten iron. This proceeds from the moon which derives its radiance from the stars, and not from the earth, because this is darkened. . . . C.A. 243 v. a

The image of the sun is all in all the water which sees it, and all in every minutest part of it.

This is proved because there are as many images of the sun as there are positions of the eyes which see the water between themselves and the sun.

Moreover as the eye moves when carried along the line of the ship it sees the image of the sun moving along the same line as that of the movement of the eye; but it will not be parallel for as the sun moves to the west the line of the images moves in a curve towards the sun, in such a way as to seem finally to unite with the image of the sun when it has reached the horizon.

If the ship's movement be to the south and the sun is in the middle of the heaven the line of the image of the sun will be curved, and it will always go on extending itself, so that at the last it will unite with the sun on the horizon and the image will seem equal in size to this sun.

C.A. 243 v. b

How bodies send forth from themselves their form heat and potency:

When the sun during an eclipse assumes the shape of a crescent, take a thin plate of iron and make a small hole in it, and turn the face of this plate towards the sun, holding a sheet of paper behind it at a distance of half a braccio, and you will see the image of the sun appear on this sheet in the shape of a crescent, similar in form and colour to its cause.

Quality of the sun:

The sun has substance, shape, movement, radiance, heat and generative power; and these qualities all emanate from itself without its diminution. C.A. 270 v. b

The solar rays after penetrating the little holes which come between the various rounded particles of the clouds take a straight and continuous course to the ground where they strike, illuminating with their radiance all the air through which they pass. C.A. 297 v. a

If the moon is a mirror of our earth, when it is at the full the earth will be half dark and half illuminated, or perhaps more than half dark.

And of dark things we cannot discern the shapes of the objects which are within their boundaries.

The adversary says that the light of the moon illumines the portion of the earth seen by it, and for this reason, as the earth is surrounded by water, that only the water reflects the light of the moon, and the earth as it is not smooth or polished in its surface as is the water, does not transmit the image of itself to this water, and so it remains dark, and thus our water shines in the moon with the darkness of the islands which it surrounds. C.A. 300 r. b

The moon has every month a winter and a summer.

And it has greater colds and greater heats and its equinoxes are colder than ours.

C.A. 303 v. b

How it is possible for the quantity of the images of the sun to pass through the indivisible point of the primitive into the derivative pyramid:

The sun is composed of a very great number of indivisible parts; and although this sun is possessed of bodily substance its powers are incorporeal consisting of heat and radiance; and since an incorporeal power has no substance not having substance it does not occupy space, and not occupying space it does not close the aperture, and consequently the passage through this aperture to and fro is permitted to each spirit at the same time.

It is possible that the solar rays reduced through a pyramid to a point by the concave mirror is redoubled in warmth and radiance; as these rays are in the derived pyramid they are thrown back by a similar mirror to an equal distance from the point.

C.A. 347 v. a

OF THE CIRCLES OF THE MOON

I find that those circles which at night seem to surround the moon, varying in circumference and in their degree of redness, are caused by the different degrees of thickness of the vapours which are situated at different altitudes between the moon and our eyes. And the circle that is larger and less red is in the first part lower than the said vapours; the second, being less, is higher and appears redder, because it is seen through two sets of vapours; and so the higher they are the smaller and the redder will they appear, for between the eye and them there will be more layers of vapours, and this goes to prove that where there appears greater redness, there is a greater quantity of vapours.

C.A. 349 v. e

BURNING MIRROR [*sketch*]

As many times as the point of the solar pyramid cut in any part whatever is contained in its base so many times is it hotter than this base.

A 54 r.

WHAT THE MOON IS

The moon is not luminous in itself, but it is well fitted to take the characteristics of light after the manner of the mirror or of water or any

other shining body; and it grows larger in the east and in the west like the sun and the other planets, and the reason of this is that every luminous body grows larger as it becomes more remote.

It may be readily understood that every planet and star is farther away from us when in the west than when it is overhead, by about three thousand five hundred [miles] according to the proof given at the side [of the page];[1] and if you see the sun and moon reflected in water which is near at hand it will seem to be the same size in the water as it does in the sky, while if you go away to the distance of a mile it will seem a hundred times as large. And if you see it reflected in the sea at the moment of its setting the image of the sun will seem to you to be more than ten miles long, because it will cover in the reflection more than ten miles of sea. And if you were where the moon is, it would appear to you that the sun was reflected over as much of the sea as it illumines in its daily course, and the land would appear amid this water like the dark spots that are upon the moon, which when looked at from the earth presents to mankind the same appearance that our earth would present to men dwelling in the moon.

OF THE NATURE OF THE MOON

When all that we can see of the moon is illumined it gives us its maximum of light, and then from the reflection of the rays of the sun which strike upon it and rebound towards us its ocean throws off less moisture to us, and the less light it gives the more it is harmful.

A 64 r.

EXPLANATION OF WHY THE SUN SEEMS LARGER IN THE WEST

Certain mathematicians contend that the sun grows larger when it is setting, because the eye sees it continually through atmosphere of greater density, alleging that objects seen through mist and in water seem larger.

To this I reply that this is not the case, for the things seen through the mist are similar in colour to those which are at a distance, but as they do not undergo the same process of diminution, they appear greater in size.

[1] Here the margin of the MS. contains a diagram representing the earth with the sun shown in two positions.

In the same way nothing seems larger in smooth water, and this you may prove by tracing upon a board which is placed under water.

The real reason why the sun grows larger is that every luminous body appears larger, as it is farther away.

A 64 v.

PRAISE OF THE SUN

If you look at the stars without their rays, — as may be done by looking at them through a small hole made with the extreme point of a fine needle and placed so as almost to touch the eye, — you will perceive these stars to be so small that nothing appears less; and in truth the great distance gives them a natural diminution, although there are many there which are a great many times larger than the star which is our earth together with the water. Think, then, what this star of ours would seem like at so great a distance, and then consider how many stars might be set longitudinally and latitudinally amid these stars which are scattered throughout this dark expanse. I can never do other than blame those many ancients who said that the sun was no larger than it appears, — among these being Epicurus; and I believe that such a theory is borrowed from the idea of a light set in our atmosphere equidistant from the centre [of the earth]; whoever sees it never sees it lessened in size at any distance, and the reasons of its size and potency I shall reserve for the Fourth Book.

But I marvel greatly that Socrates should have spoken with disparagement of that body, and that he should have said that it resembled a burning stone, and it is certain that whoever opposes him in such an error can scarcely do wrong. I could wish that I had such power of language as should avail me to censure those who would fain extol the worship of men above that of the sun, for I do not perceive in the whole universe a body greater and more powerful than this, and its light illumines all the celestial bodies which are distributed throughout the universe.

All vital principle descends from it, since the heat there is in living creatures proceeds from this vital principle; and there is no other heat or light in the universe as I shall show in the Fourth Book, and indeed those who have wished to worship men as gods, such as Jupiter, Saturn, Mars and the like, have made a very grave error seeing that even if a man were as large as our earth he would seem like one of the least of the stars, which appears but a speck in the universe; and seeing also that

these men are mortal and subject to decay and corruption in their tombs.

The *Spera*, and Marullo, and many others praise the Sun.

F 5 r. and 4 v.

The stars are visible by night and not by day owing to our being beneath the dense atmosphere which is full of an infinite number of particles of moisture. Each of these is lit up when it is struck by the rays of the sun and consequently the innumerable radiant particles veil these stars; and if it were not for this atmosphere the sky would always show the stars against the darkness.

F 5 v.

Epicurus perhaps perceived that the shadows of columns striking the opposite walls were equal in diameter to the column from which they proceeded. As therefore the mass of the shadow from beginning to end was a parallelogram he thought he might infer that the sun also was opposite to this parallelogram and as a consequence would not be larger than this column, not perceiving that such a diminution of the shadow would be imperceptible on account of the great distance of the sun.

If the sun were smaller than the earth, the stars in a great part of our hemisphere would be without light: this is contrary to Epicurus who says that the sun is only as large as it appears.

F 6 r.

Epicurus says that the sun is as large as it shows itself; as therefore it appears to be a foot we have to reckon it as such.

It would follow that when the moon obscured the sun the sun would not surpass it in size as it does; therefore the moon being smaller than the sun the moon would be less than a foot, and consequently when our earth obscured the moon it would be less by a finger's breadth, seeing that if the sun be a foot across and our earth casts a pyramidal shadow towards the moon it is inevitable that the luminous body which is the cause of the shaded pyramid must be greater than the opaque body which casts this pyramid.

F 8 v.

A calculation of how many times the sun will go into its course in twenty four hours:

Make a circle and set it to face south after the manner of sundials; place a rod in the middle of it so that its length is pointing to the centre of the circle and note the shadow made by the sun from this rod upon

the circumference of the circle, and let us say that the breadth of the shadow is all *a n* (diagram). Now measure how many times this shadow will go into this circumference of the circle, and this will be the number of times that the solar body will go into its course in twenty four hours. In this way one may see whether Epicurus was right in saying that the sun is as large as it seems to be, for as the apparent diameter of the sun is about a foot and as the sun would go a thousand times into its course in twenty four hours, the length of its course would be a thousand feet, that is five hundred braccia, which is the sixth of a mile; so then the course of the sun between day and night would be the sixth part of a mile, and this venerable snail the sun would have travelled twenty five braccia an hour.

F 10 r.

THE ORDER OF PROVING THAT THE EARTH IS A STAR

First explain the mechanism of the eye, then show how the scintillation of each star originates in the eye, and why the scintillation of one star is greater than that of another. And how the rays of the stars originate in the eye. I affirm that if the scintillation of the stars was as it appears, in the stars, this scintillation would show itself as widely extended as the body of the star; and since it is larger than the earth this movement made instantaneously would swiftly be found to cause the star to seem double in size. See afterwards how the surface of the air on the confines of the fire, and the surface of the fire at its boundary, is that in which the solar rays penetrating carry the resemblance of the heavenly bodies, large in their rising and setting and small when they are in the centre of the sky.

F 25 v.

AN EXPERIMENT IN ORDER TO SHOW HOW RAYS PENETRATE LIQUID BODIES

Make two vessels each of parallel sides, the one four fifths of the other and of equal height. Then fix one within the other as you see in the drawing, and cover outside with colour and leave an opening of the size of a lentil, and allow a ray of the sun to enter there which makes its exit through another dark hole or by the window. Then observe whether the ray that passes within the water enclosed between the two vessels keeps the direction that it has outside or no; and from this deduce your rule.

In order to see how the solar rays penetrate this curve of the sphere of the air have two balls made of glass one twice as large as the other, and let them be as round as possible. Then cut them in half, place one inside the other, close them in front and fill them with water, then let the solar ray pass within as you have done above, and observe whether the ray is bent or curved and from this deduce your rule. And in this way you can make an infinite number of experiments.

Observe as you place yourself with your eye in the centre of the ball whether the light of a candle keeps its size or no.

F 33 v.

OF THE SUN

Some say that the sun is not hot because it is not the colour of fire but is much paler and clearer. To these we may reply that when liquified bronze is at its maximum of heat it most resembles the sun in colour, and when it is less hot it has more of the colour of fire.

F 34 v.

The solar rays reflected by the surface of the undulating water cause the image of the sun to seem continuous over all that water which is between the universe and the sun.

F 38 v.

Why the image of the sun is all in all the sphere of the water which sees the sun and all in each part of the said water:

All the sky which sees the part of the sphere of the water seen by the sun sees all this water covered by the image of the sun, and each part of the sky sees all.

The surface of the water without waves lights equally the places struck by the reflected rays of the image of the sun in the water.

The image of the sun is unique in the sphere of the water seen by the sun, which shows itself however to all the sky that finds itself before it, and every point of this sky itself sees an image, and that which sees one in one position is seen by the other in another position, in such a way that no part of the sky sees it all.

That image of the sun will cover a greater space in the surface of the water which is seen from a place more distant from it.

F 39 r.

How the earth is not in the centre of the circle of the sun, nor in the centre of the universe, but is in fact in the centre of its elements which accompany it and are united to it. And if one were to be upon the moon,

then to the extent to which it together with the sun is above us,[1] so far below it would our earth appear with the element of water, performing the same office as the moon does for us.

F 41 V.

All your discourse points to the conclusion that the earth is a star almost like the moon, and thus you will prove the majesty of our universe; and thus you will make a discourse concerning the size of many of the stars according to the authorities.

F 56 r.

Whether the friction of the heavens makes a sound or no:

Every sound is caused by the air striking a dense body, and if it is made by two heavy bodies one with another it is by means of the air that surrounds them; and this friction wears away the bodies that are rubbed. It would follow therefore that the heavens in their friction not having air between them would not produce sound. Had however this friction really existed, in the many centuries that these heavens have revolved they would have been consumed by their own immense speed of every day. And if they made a sound it would not be able to spread, because the sound of the percussion made underneath the water is but little heard and it would be heard even less or not at all in the case of dense bodies. Further in the case of smooth bodies the friction does not create sound, and it would happen in a similar manner that there would be no sound in the contact or friction of the heavens. And if these heavens are not smooth at the contact of their friction it follows that they are full of lumps and rough, and therefore their contact is not continuous, and if this is the case the vacuum is produced, which it has been concluded does not exist in nature. We arrive therefore at the conclusion that the friction would have rubbed away the boundaries of each heaven, and in proportion as its movement is swifter towards the centre than towards the poles it would be more consumed in the centre than at the poles; and then there would not be friction any more, and the sound would cease, and the dancers would stop, except that the heavens were turning one to the east and the other to the north.

F 56 V.

Whether stars have light from the sun or in themselves:

It is said that they have light in themselves, since if Venus and Mercury had no light of their own, when they come between our eye and the

[1] MS. sotto. I have followed M. Ravaisson-Mollien's rendering.

sun they would darken as much of the sun as they cover from our eyes. This however is false, because it has been proved how a dark object placed against a luminous body is surrounded and entirely covered by the lateral rays of the remainder of this luminous body, and so it remains invisible. As is shown when the sun is seen through the ramification of leafless trees in the far distance these branches do not conceal any part of the sun from our eyes. The same thing happens with the above mentioned planets, for though they are themselves without light they do not as has been said cover any part of the sun from our eyes.

It is said that the stars at night appear most brilliant in proportion as they are higher up, and that if they have no light of their own the shadow cast by the earth when it comes between them and the sun would come to darken them, since these stars neither see nor are seen by the solar body.

But those who say this have not considered that the pyramidal shadow of the earth does not reach many of the stars, and that in those which it does reach the pyramid is so diminished that it covers little of the body of the star, and all the rest is illuminated by the sun.

F 57 r.

Why the planets appear greater in the east than above us, though it ought to be the opposite seeing that they are three thousand five hundred miles nearer to us when they are in the middle of the sky than when they are on the horizon:

All the degrees of the elements through which pass the images of the celestial bodies which come to the eye are curved, and the angles by which the central line of these images penetrates there are unequal, and the distance is greater as is shown by the excess of *a b* over *a d*; and by the Ninth of the Sixth the size of heavenly bodies on the horizon is proved.

F 60 r.

Explain the earth with its longer and shorter day in the north and in the south, and do the same for the moon and define them accurately.

F 63 r.

DARKNESS OF SUN MOON AND EARTH

The moon has its days and nights as has the earth: the night in the part which does not shine and the day in that which does.

Here the night of the moon sees the light of the earth, that is to say of its water, grow dim — and the darkened water sees the darkness of the sun, and to the night of the moon there is lacking the reverberation of the solar rays which are reflected there from this earth.

In this other figure it is shown that the day of the moon is darkened and the night of the earth remains deprived of the solar rays reflected from the moon.

When the moon is in the east and the sun in the west, all the day that the moon enjoyed, such as it was with the sun in the west, is changed into night.

Such day as has the moon which from the east looks at the sun in the west will all be night when this moon is with the sun in the west.

F 64 v.

OF THE RAINBOW

Whether the rainbow is produced by the eye, that is its curve, or by the sun by means of the cloud:

The mirror does not take any images except those of visible bodies, and the images are not produced without these bodies; therefore if this arch is seen in the mirror, and the images converge there which have their origin in this rainbow, it follows that this arch is produced by the sun and by the cloud.

The rainbow is seen in the fine rains by those eyes which have the sun behind and the cloud in front, and a perpetually straight imaginary line which starts from the centre of the sun and passes through the centre of the eye will end in the centre of the arch.

And this arch will never be seen by one eye in the same position as by the other eye; it will be seen in as many positions of the cloud where it is formed as there are eyes that see it.

Therefore this arch is all in all the cloud where it is produced, and all in each of the positions in which it may find itself, and so it will appear larger or smaller, half, whole, double, triple.

If two spheres of metal transmit the solar rays into a dark place, as the water is turned into vapour it will make the solar spectrum[1] long in shape.

This occurs also with the water turned into vapour when the solar ray is passing into a dark place with the sun behind it, and also with the light of torches or of the moon.

F 67 v.

How the earth in performing the function of the moon has lost a considerable amount of the ancient light in our hemisphere by the

[1] Thus Rav.-Moll. — 'le spectre solaire.' MS. 'arco iris'.

lowering of the waters, as is proved in Book Four 'Of the Earth and the Waters':

The earth is heavy in its sphere, but so much the more as it is in a lighter element.

Fire is light in its sphere, and so much the more as it is in a heavier element.

No simple element has gravity or levity in its own sphere, and if a bladder filled with air weighs more in the scales than an empty one, this is because this air is compressed; and fire might be so compressed that it would be heavier than the air or equal to the air, and perhaps heavier than the water, and making itself equal to the earth. F 69 v.

This will follow the treatise on light and shade:

The extremities of the moon will be more illuminated and will show themselves more luminous because nothing will appear in them except the summits of the waves of its waters; and the shadowy depths of the valleys of these waves will not change the images of those luminous parts which from the summits of these waves come to the eye. F 77 v.

Omne grave tendit deorsum nec perpetuo potest sic sursum sustineri, quare jam totalis terra esset facta spherica.[1]

THE SPOTS ON THE MOON

Some have said that vapours are given off from the moon after the manner of clouds, and are interposed between the moon and our eyes. If this were the case these spots would never be fixed either as to position or shape; and when the moon was seen from different points, even although these spots did not alter their position, they would change their shape, as does a thing which is seen on different sides. F 84 r.

OF THE SPOTS ON THE MOON

Others have said that the moon is made up of parts, some more, some less transparent, as though one part were after the manner of alabaster, and another like crystal or glass. It would then follow that when the rays of the sun struck the less transparent part the light would stay on the surface, and consequently the denser part would be illuminated, and the transparent part would reveal the shadows of its obscure

[1] Every heavy substance presses downwards, and thus cannot be upheld perpetually; wherefore the whole earth has been made spherical.

depths. Thus then they define the nature of the moon, and this view has found favour with many philosophers, and especially with Aristotle; but nevertheless it is false, since in the different phases which the moon and the sun frequently present to our eyes we should be seeing these spots vary, and at one time they would appear dark and at another light. They would be dark when the sun is in the west and the moon in the centre of the sky, because the transparent hollows would then be in shadow, as far as the tops of their edges, since the sun could not cast its rays into the mouths of these same hollows; and they would appear bright at full moon, when the moon in the east faces the sun in the west; for then the sun would illumine even the lowest depths of these transparent parts, and in consequence as no shadow was created, the moon would not at such times reveal to us the above-mentioned spots, and so it would be, sometimes more sometimes less, according to the change in the position of the sun to the moon, and of the moon to our eyes, as I have said above.

F 84 v.

It has also been said that the spots on the moon are created in the moon itself, by the fact of it being of varying thinness or density. If this were so, then in the eclipses of the moon the solar rays could pierce through some part where it is thin, as has been stated, but since we do not see this result the aforesaid theory is false.

Others say that the surface of the moon is smooth and polished, and that, like a mirror, it receives within itself the reflection of the earth. This theory is false, since the earth, when not covered by the water, presents different shapes from different points of view; so when the moon is in the east it would reflect other spots than when it is overhead or in the west, whereas the spots upon the moon, as seen at full moon, never change during the course which it makes in our hemisphere. A second reason is that an object reflected in a convex surface fills only a small part of the mirror, as is proved in perspective. The third reason is that when the moon is full it only faces half the orb of the illuminated earth, in which the ocean and the other waters shine brightly, while the land forms spots amid this brightness; and consequently the half of our earth would be seen girded round about by the radiance of the sea, which takes its light from the sun, and in the moon this reflection would be the least part of that moon. The fourth reason is that one radiant body cannot be reflected in another, and consequently as the sea derives its

radiance from the sun, as does also the moon, it could not show the reflected image of the earth, unless one also saw reflected there separately the orb of the sun and of each of the stars which look down upon it.

F 85 r.

SOLAR RAYS

The solar rays pass through the cold region of the air and do not change their nature. They pass through glasses filled with cold water and lose nothing of their nature thereby; and whatever may be the transparent place through which they pass it is as though they passed through so much air.

And if you maintain that the cold rays of the sun are clothed with the heat of fire as they traverse its element, just as they assume the colour of the glass they penetrate, it would follow that in penetrating the cold region they put on this mantle of cold after they have already put on the said mantle of heat, and thus the cold would counteract the heat, and therefore the solar rays would come to us deprived of heat, and as this is not confirmed by experience such method of reasoning as to the sun being cold is vain.

But if you were to say that the cold through which the fiery rays of the sun pass somewhat modifies the excessive heat of these rays it would follow from this that one would feel greater heat on the high peaks of the Caucasus the mountain of Scythia than in the valleys, because the mountain towers above the middle regions of the air, and no clouds are found there nor anything that grows.

And if you say that these solar rays thrust towards us the element of fire from whence they pass by local movement, this cannot be admitted because the local movement of such [a volume of] air cannot occur without the passing of a period of time, and this is greater in proportion as the sun is more on the horizon, for when there it is 3,500 miles farther away from us than when it is in the centre of our heaven. If it acted thus it would cool the part of our horizon opposite to it, because it would carry away in its rays such part of the element of fire opposite to it as it penetrated.

If the lesser fire is attracted to and deflected by the greater fire as one sees happen by experience, it must needs be that the sun draws the element of fire to itself rather than that it banishes it from itself and drives it towards us.

And the heat of the fire does not descend unless it follows burning

matter, and in acting thus it is material and in consequence it is visible.

F 86 r.

How if the moon is polished and spherical the image of the sun upon it is powerfully luminous, and is only on a small part of its surface:

You will see the proof of this by taking a ball of burnished gold and placing it in the darkness and setting a light at some distance from it. Although this illuminates about half the ball, the eye only sees it reflected on a small part of its surface, and all the rest of the surface reflects the darkness which surrounds it. For this reason it is only there that the image of the light is apparent, and all the rest remains invisible because the eye is at a distance from the ball. The same thing would happen with the surface of the moon if it were polished, glittering and solid, as are bodies which have a reflecting surface.

Show how if you were upon the moon or upon a star our earth would appear to you to perform the same function for the sun as now the moon does. And show how the reflection of the sun in the sea cannot itself appear a sun as it does in a flat mirror.

F 93 r.

My book attempts to show how the ocean with the other seas makes our world by means of the sunshine after the manner of a moon, and to the more remote worlds it appears a star; and this I prove.

Moon cold and moist.

Water is cold and moist.

Our sea has the same influence on the moon as the moon has on us.

F 94 v.

EXPLANATION OF THE MOON WITH THE IMAGE OF THE SUN

If the sun *f* reflected in the surface of the water *n m* should seem to be at *d* (that is to say seems to be as far below the water as it is above), and to the eye *b* appears to be of the size *a*, and this image doubles itself as the eye is removed from *b* to *c*, how much would this image grow if the eye were removed from *c* to the moon?

Work with the rule of three and you will see that the light which there is in the moon on its fifteenth day can never be the light that this moon receives from it being spherical; therefore it is necessary that this moon contains water.

G 20 r.

[Of the nature of the sun's heat]

OF THE PROOF THAT THE SUN IS HOT BY NATURE AND NOT BY POWER

That the sun is hot in itself by nature and not by power is shown very distinctly by the radiance of the solar body on which the human eye cannot continue to look. And this moreover the rays reflected by concave mirrors show very clearly, for when their percussion is of such radiance that the eye cannot endure it, this percussion will have a radiance resembling that of the sun in its own position. And the truth of this is proved by the fact that if such a mirror has such a concave surface as is required in order to produce this ray, no created thing will be able to support the heat of such percussion of ray reflected from any mirror. And if you say that the mirror also is cold and yet throws warm rays, I say in reply that the ray comes from the sun and will have to pass through the mirror in order to resemble its cause and can pass through whatever medium it wishes. . . .

The ray of the concave mirror having passed across the windows of the furnaces where are cast . . . has not great heat nor any longer has whiteness.

G 34 r.

THE SOLAR RAYS

Where there is the finer and more rarefied medium the solar rays meet with a less resistance and where there is the less resistance it is less permeated by the nature of the agent. Consequently for this reason one may infer that where the air is more rarefied the percussion of the said solar rays transmits less radiance, and as a consequence it is darker, and so also conversely.

K 118 [38] r.

A proof how the nearer you are to the source of the sun's rays the greater will the sun appear when reflected upon the sea:

If the sun produces its radiance from its centre fortified by power from the whole body it must needs be that the farther its rays proceed from it the more they go on separating. This being so when you have your eye near water that reflects the sun, you see a very small part of the sun's rays carrying upon the surface of the water the form of the sun reflected; and if you are nearer to the sun as would be the case when the sun is at the meridian and the sea is to the west, you will see the sun reflected in the sea of very great size, because as you are nearer to the sun

your eye as it takes the rays near to the point takes in more of them and so greater radiance ensues. For this reason it might be proved that the moon is another world similar to ours, and that the part of it which shines is a sea that reflects the sun and the part which does not shine is earth.

MS. 2038 Bib. Nat. 16 v.

If you keep the details of the spots of the moon under observation you will often find great differences in them, and I have myself proved this by making drawings of them. And this comes about because the clouds rise from the waters of the moon and come between the sun and this water, and with their shadows cut off the rays of the sun from it, and consequently it remains dark because it cannot reflect the solar body.

B.M. 19 r.

OF THE MOON

As wishing to treat of the nature of the moon it is necessary in the first place that I should describe the perspective of mirrors, whether flat concave or convex, and first of all what is meant by a luminous ray and how it is refracted by various kinds of media. Then whether the reflected ray is more powerful if the angle of incidence be acute or a right angle or obtuse, or if the surface be convex or flat or concave, or the substance opaque or transparent. Furthermore how it is that the solar rays which strike the waves of the sea show themselves of the same width in the angle close to the eye as in the farthest crest of the waves on the horizon, notwithstanding which the solar radiance reflected by the waves of the sea is of the shape of a pyramid, and as a consequence at every stage of distance acquires an access of breadth, although to our sight it may appear parallel.

Nothing extremely light is opaque.

Nothing that is lighter remains below what is less light.

Whether the moon has its station in the midst of its elements or no.

If it has not a particular station as has the earth in its elements why it does not fall to the centre of our elements.

And if the moon is not in the midst of its elements and does not descend it is therefore lighter than the other element.

And if the moon is lighter than the other element why it is solid and not transparent.

Of things of different size which when placed at different distances show themselves equal, there will be the same proportion between their distances as there is between their sizes. B.M. 94 r.

OF THE MOON

The moon has no light of itself but so much of it as the sun sees, it illuminates. Of this illuminated part we see as much as faces us. And its night receives as much brightness as our waters lend it as they reflect upon it the image of the sun, which is mirrored in all those waters that face the sun and the moon.

The crust or surface of the water of which the sea of the moon and the sea of our earth are composed is always wrinkled whether little or much or more or less; and this ruggedness is the cause of the expansion of the innumerable images of the sun which are reflected in the hills and valleys and sides and crests of the innumerable furrows, that is in as many different spots in each furrow as there are different positions of the eyes that see them. This could not happen if the sphere of water which in great part covers the moon were of uniform roundness, because then there would be an image of the sun for every eye, and its reflection would be distinct and the radiance of it would always be spherical in shape, as is clearly shown in the gilded balls placed on the summits of lofty buildings. But if these gilded balls were furrowed or made up of many small globules like mulberries, which are a black fruit composed of minute round balls, then each of the parts of this rounded mass visible to the sun and to the eye will reveal to the eye the radiance produced by the reflection of the sun. And thus in the same body there will be seen many minute suns and very often on account of their great distance they will blend one with another and seem continuous.

The lustre of the new moon is brighter and more powerful than when it is full; and this is due to the fact that the angle of its incidence is much more obtuse in the new moon than in the full moon, where the angles are extremely acute, and the waves of the moon reflect the sun both on their hollows and on their crests, and the sides remain dark. But at the sides of the moon the troughs of the waves do not see the sun, for it only sees the crests of these waves, and in consequence the reflections are less frequent and more mingled with the shadows of the valleys. And this intermixture of shaded and luminous images all blending together comes to the eye with only a moderate amount of radiance, and at its edges it will be even darker, because the curve of the side of these waves will be insufficient to reflect the rays which it receives to the eye.

For which reason the new moon by its nature reflects the solar rays

more towards the eye through these last waves than through any other place, as is shown by the figure of the moon striking with the rays *a* on the wave *b* and reflected in *b d* where the eye *d* is situated. And this cannot happen at full moon, where the solar ray standing in the west, strikes the last rays of the moon in the east from *n* to *m*, and does not reflect towards the eye in the west; but leaps back to the east, slightly bending the direction of this solar ray; and so the angle of the incidence is very great.

The countless images which are reflected by the innumerable waves of the sea from the solar rays that strike upon these waves, cause a continuous and far reaching splendour upon the surface of the sea.

The moon is an opaque and solid body, and if on the contrary it were transparent it would not receive the light of the sun.

B.M. 94 V.

You have to prove how the earth performs all those same functions towards the moon which the moon does towards the earth.

The moon does not shine with its reflected light as does the sun, because the moon[1] does not receive the light of the sun on its surface continuously, but in the crests and hollows of the waves of its waters, through the sun being indistinctly reflected in the moon through the mingling of the shadows which are above the waves that shed the radiance. Its light therefore is not bright and clear as is that of the sun.

B.M. 104 R.

To observe the nature of the planets have an opening made in the roof and show at the base one planet singly: the reflected movement on this base will record the structure of the said planet, but arrange so that this base only reflects one at a time.

B.M. 279 V.

The circles of the celestial spheres together with the elements equally drive and thrust away from themselves everything that has weight, whence for this reason it must be confessed that it is necessary for the centres of these spheres to meet and become stationary.

Whence through this it is necessary to confess that the things falling towards the centre are rather thrust from above than drawn by this centre downwards; because if it were possible that this earth should be withdrawn in part in such a manner that the space occupied by the

[1] MS. has 'il lume della luna'.

position of the earth were filled with air, you would see a stone thrown off from our world into this air become stationary in the centre of the two elements and of the spheres.

Forster III 6 v.

The centre of the world cannot be the centre of the universal circles made by the course of the glittering stars, because in a like position it cannot be taken for granted that the universal parts of the earth, the encompasser and enveloper of this centre, are not of equal weight when removed at an equal distance from this centre.

Naturally every heavy thing is thrust towards the centre because the centre is farthest removed from these expelling and rotatory forces.

I conclude: the centre of the weight of the earth with the water is the centre of the spheres and not the centre of the mass of this world.

Forster III 7 r.

These heavy parts which were thrust down from there above, have of themselves already created bodies which always stand in continual desire of returning there above.

Forster III 8 r.

The sun does not move.

Quaderni V 25 r.

Between the sun and us there is darkness, and therefore the air appears blue.

Windsor MSS. R 868

If you wish to prove that the moon appears larger than it is when it reaches the horizon, you take a lens convex on the one side and concave on the other and place the concave side to your eye and look at the object beyond the convex surface; and by this means you will have made a true imitation of the atmosphere which is enclosed between the sphere of fire and that of water, for this atmosphere is concave towards the earth and convex towards the fire.

Windsor: Drawings 12326 v.

Memorandum that I have first to show the distance of the sun from the earth and by means of one of its rays passing through a small hole into a dark place to discover its exact dimensions, and in addition to this by means of the sphere of water to calculate the size of the earth.

And the size of the moon I shall discover as I discover that of the sun, that is by means of its ray at midnight when it is at the full.

Leic. I r.

Reply to Maestro Andrea da Imola who said that the solar rays reflected by the surface of the convex mirror intermingled and became lost at a short distance, and that for this reason it is altogether denied that the luminous side of the moon is of the nature of a mirror, and that in consequence this light is not produced by the innumerable multitude of the waves of that sea, which I have demonstrated to be that part of the moon which is illuminated by the solar rays. Leic. 1 v.

OF THE MOON

No solid body is lighter than air.

As we have proved that the part of the moon which shines consists of water and it serves the body of the sun as a mirror which reflects the radiance it receives from it; and that if this water were without waves it would show itself as small but of a radiance almost equal to that of the sun, it is necessary now to show whether the moon is a heavy or light body. Thus if it were a heavy body — considering that in progression upwards from the earth at every stage of altitude there is an accession of lightness, inasmuch as water is lighter than earth, air than water and fire than air and so continuing in succession — it would seem that if the moon had density, as it has, it would have weight, and that having weight the space in which it finds itself would not be able to support it, and as a consequence it would have to descend towards the centre of the universe and to join itself to the earth; or if not the moon itself its waters at any rate would fall away and become lost to it and would fall towards the centre leaving the moon stripped of them and devoid of radiance. The fact however that these events do not occur as might with reason have been anticipated is a clear sign that the moon is clothed with her own elements, namely water air and fire and so sustains itself by itself in that part of space as does our earth with its elements in this other part of space; and that the heavy bodies perform the same function in its elements which the other heavy bodies do in ours.

[*Diagram*] sun, moon, earth.

When the eye in the east sees the moon in the west near the setting sun it sees it with its shaded part surrounded by the luminous part; of which light the lateral and upper portions are derived from the sun and the lower portion from the western ocean, which still receives the solar rays and reflects them in the lower seas of the moon, and moreover it imparts as much radiance to the whole of the shaded part of the moon

as the moon gives to the earth at midnight, and for this reason it does not become absolutely dark. And from this some have believed that the moon has in part a light of its own in addition to that which is given it by the sun, and that this light is due to the cause already mentioned, namely that our seas are illumined by the sun.

[*Diagram*] moon, solar body, earth.

Further it might be said that the circle of radiance which the moon shows when it is in the west together with the sun is derived entirely from the sun, when its position with regard to the sun and the eye is as is shown above.

Some might say that the air which is an element of the moon as it catches the light of the sun as does our atmosphere was that which completes the luminous circle on the body of the moon.

Some have believed that the moon has some light of its own, but this opinion is false, for they have based it upon that glimmer which is visible in the middle between the horns of the new moon, which appears dark where it borders on the bright part, and where it borders on the darkness of the background seems so bright that many have assumed it to be a ring of new radiance which completes the circle where the radiance of the tips of the horns illuminated by the sun ceases.

And this difference in the background arises from the fact that the part of it which borders on the illuminated portion of the moon, by comparison with that brightness shows itself darker than it is, and in the part above where appears a portion of a luminous circle of uniform breadth it comes about that there the moon being brighter than the medium or background upon which it finds itself, in comparison with this darkness shows itself on that extremity brighter than it is, this brightness at such a time being derived from our ocean and the other inland seas, for they are at that time illumined by the sun which is then on the point of setting, in such a way that the sea then performs the same office for the dark side of the moon as the moon when at the full does for us when the sun is set, and there is the same proportion between that small quantity of light on the dark side of the moon and the brightness of the illuminated part, as there is between . . .

If you want to see how much brighter the shaded part of the moon is than its background, cover from your eye with your hand or with some other object farther away the luminous part of the moon, so that . . .

Leic. 2 r.

I say that as the moon has no light of its own, but is luminous, it must needs be that this light is caused by some other body: this being so it is of the nature of a spherical mirror; and if it is spherical it takes the light pyramid-wise; and of this pyramid the sun is the base, and its angle ends in the centre of the body of the moon, and it is cut by the surface of this body, and only takes as much as corresponds to the section of this pyramid on its surface. And to the human eye this moon would only seem the size of this section of the pyramid. Whence there would follow from the light of the moon the contrary effect to that which experience shows us; for this is that as the moon turns it has its whole orb luminous as is shown us by this; for this clearly shows us that this lunar body has more than half its orb illuminated. But this would not happen if it were a polished body like the mirrors; consequently for this reason we are constrained to admit, by my fifth [rule], that the surface of the moon is furrowed; and this roughness only exists in liquid bodies when they are stirred by the wind, as we have seen with the sea how the sun is reflected by tiny waves near to the eye, and stage by stage over a distance of more than forty miles these illuminated waves grow larger. Wherefore we conclude that the luminous part of the moon is water, which if it were not in movement would not be luminous to the same degree; but by the movement of this water which has been stirred up by the winds it becomes filled with waves; and every wave takes the light from the sun; and the great multitude of waves beyond number reflect the solar body an infinite number of times; and the sun thus reflected will be as bright as the sun, for as is seen when the water does not move it gives back the sun to the eye in the pristine splendour that it has by nature.

But the shadows also are beyond number as well as the waves, and these are interspersed between the waves; and their shapes blend with the shapes of the images of the sun, which are upon the waves; and each shadow shape becomes blended with a luminous shape and so they come to obscure the luminous rays and make them weak, as is clearly shown us by the light of the moon. And when the sea of the moon is stirred to tempest by the winds the waves are larger and the lights less frequent and the enlarged shadows intermingle more with the sparse images of the sun upon the waves, and for this reason the moon becomes less luminous. But when the moon is in its circle and has a position at about the centre of our hemisphere, each wave shows the reflection of the sun both in the centre of the valleys interposed between the waves and in the

summits of these waves; and for this reason the moon shows itself more luminous than ever, through having the number of the parts in light doubled.

It shows itself also strongly luminous a short time after its turn, because the sun which stands beyond the moon, striking the waves upon their summits, when these summits are near together and seem almost to clash one against another when the eye is on this side, causes the shadows which come between the waves not to transmit to the eye their images mingled with the luminous images; and for this reason the light of the moon is more powerful.

And what is proved of one luminous body holds true of all the rest.

Leic. 30 r.

Of the moon: all the objections of the adversary, to say that in the moon there is no water.

Objection: Every body thicker than the air is heavier than this air and cannot be supported upon it without other cause; and the more it rises the less it is resisted by its medium: therefore, if there were water in the moon, it would despoil the moon of itself, and would come to cover our earth, because in this moon the water would be above its air. Here the answer is that if there is water in the moon there is also earth there upon which this water supports itself, and consequently the other elements: and water is supported up there among the three other elements, as down here our water is among its accompanying elements; if however as the adversary holds the water had to fall from the moon, it would rather be that the moon would have to fall as being a body heavier than the water; therefore not falling it is a clear proof that the water up there and the earth are supported with their other elements just as the heavy and light elements down here are supported in space that is lighter than themselves.

The adversary says that the light of the moon, if not the whole of it, is the same in itself; and that it shows itself more or less illuminated, according as the eye sees more or less of its shaded part, that is, if it is more in the east than the west.

Here, at this point, one replies, that if the . . .

Leic. 36 v.

XII

Botany

'All seeds have the umbilical cord, which breaks when the seed is ripe. And in like manner they have matrix and secundina, as is seen in herbs and all the seeds which grow in pods.'

When a tree has had part of its bark stripped off, nature in order to provide for it supplies to the stripped portion a far greater quantity of nutritive moisture than to any other part; so that because of the first scarcity which has been referred to the bark there grows much more thickly than in any other place. And this moisture has such power of movement that after having reached the spot where its help is needed, it raises itself partly up like a ball rebounding, and makes various buddings and sproutings, somewhat after the manner of water when it boils.

Many trees planted in such a way as to touch, by the second year will have learnt how to dispense with the bark which grows between them and become grafted together; and by this method you will make the walls of the gardens continuous, and in four years you will even have very wide boards.

When many grains or seeds are sown so that they touch and are then covered by a board filled with holes the size of the seeds and left to grow underneath it, the seeds as they germinate will become fixed together and will form a beautiful clump. And if you mix seeds of different kinds together this clump will seem like jasper.

C.A. 76 r. a

The branches of plants are found in two different positions: either opposite to each other or not opposite. If they are opposite to each other the centre stem is not bent: if they are not opposite the centre stem is bent.

C.A. 305 v. a

[*Of barking trees*]

If you take away a ring of bark from the tree *d* it will wither from the ring upwards and all below will remain alive.

If you make the said ring incompletely and then graft the plant near the foot deftly, the part that has been deftly treated will be preserved and the rest will be spoilt.

B 17 v.

OF THE RAMIFICATION OF PLANTS

The plants which spread out very much have the angles of the divisions which separate their ramifications more obtuse in proportion

as their point of origin is lower down, that is nearer to the thicker and older part of the tree; whereas in the newer part of the tree the angles of its ramifications are more acute.

E 6 v.

The trunks of the trees have a bulbous surface which is caused by their roots which carry nourishment to the tree; and these excrescences have their surface of bark containing few fissures, and their intervals are hollows where the bark has become dried because the nourishment comes to it less abundantly.

G 1 r.

The shadows on transparent leaves seen from beneath are the same as those on the right side of the leaf, for the shadow is visible in transparence on the under side as well as the part in light; but the lustre can never be seen in transparence.

G 3 v.

The lowest branches of the trees which have big leaves and heavy fruits such as coco-palms, figs and the like always bend towards the ground.

The branches always start above the leaf.

G 5 r.

Young trees have more transparent leaves and smoother bark than old ones: the walnut especially is lighter in colour in May than in September.

G 8 r.

That plant will preserve its growth in the straightest line which produces the most minute ramification.

G 13 r.

OF BRANCH STRUCTURE

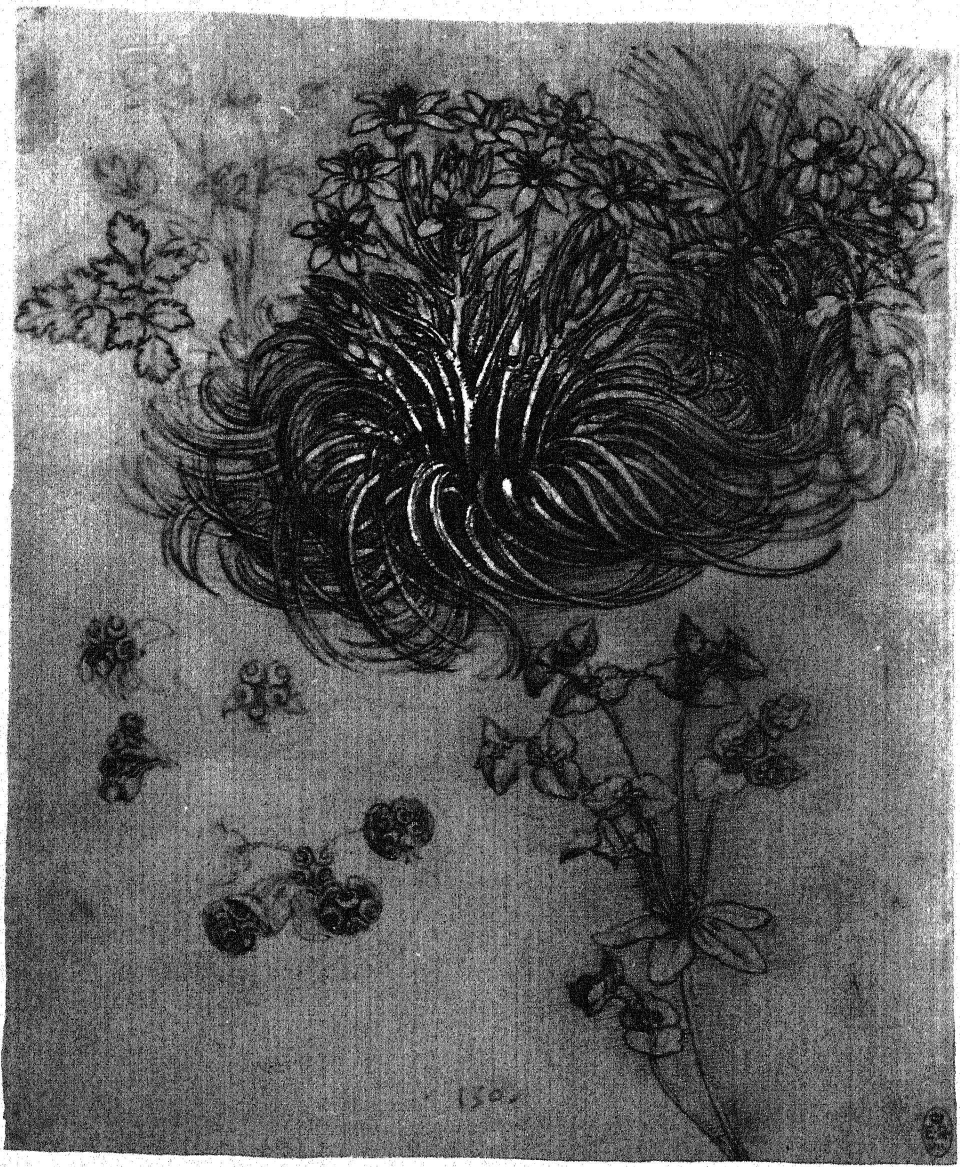
The beginning of the branch will always have the central line of its thickness taking its direction by the central line of the plant.

G 14 r.

OF THE BIRTH OF LEAVES UPON THEIR BRANCHES

The thickness of a branch is never diminished in the space there is between one leaf and another except by as much as the thickness of the eye that is above the leaf, and this thickness is lacking in the branch up to the next leaf.

Nature has arranged the leaves of the latest branches of many plants



CREEPING CROWFOOT, STAR OF BETHLEHEM, WOOD ANEMONE AND LEAFY-BRANCHED SPURGE

Royal Library, Windsor

so that the sixth is always above the first, and so it follows in succession if the rule is not impeded.

This serves two uses for the plants, the first being that as the branch or fruit springs in the following year from the bud or eye which is above it in contact with the attachment of the leaf, the water which wets this branch is able to descend to nourish the eye by the fact that the drops are caught in the axil where the leaf springs; and the second use is that when these branches grow in the succeeding year one will not cover the other, because the five branches come forth turned in five different directions and the sixth comes forth above the first but at a sufficient distance.

G 16 V.

[*Of branch structure*]

Between one ramification and the other if there are no other particular branches the tree will be of uniform thickness. And this takes place because the whole sum of the humour that feeds the beginning of this branch continues to feed it until it produces the next branch. And this nourishment or equal cause produces equal effect.

G 17 R.

Trees which divide near to the ground seldom put forth branches in the space that intervenes between them; and if however there should be one it will have but a short life and will not make much growth on account of the shadow that the one gives to the other.

There are many bends in the branches where there are none of the six lesser branches that usually surround them; for these failed in their youth, and death passed over their stumps and spread to the more vital parts.

The principal branches of the trees which rise the most are always nearer the centre of the plant than any of its brothers or sons.

G 24 V.

The small branches of the same year grow in all the parts of the tree only in those places where there were its old ramifications, produced in the order of the birth of their leaves, that is to say each is produced the one above the other.

The occasional dents in the big branches of trees are not in the same order as that of the inception of the leaves which are near to them.

Because its lesser branches never traverse such dents in their infancy

the chief branch as it carries more sap keeps its course straight for a long space.

G 25 r.

DESCRIPTION OF THE ELM

This ramification of the elm has the largest branch in front, and its smallest are the first and the penultimate when the chief branch is straight.

From the starting point of one leaf to the other is the half of the greatest length of the leaf; a little less because the leaves form an interval which is about a third the width of the leaf.

The elm has the tips of its leaves nearer the extremity of the branch than its starting point, and in width they vary but little when looked at from the same side.

G 27 r.

The leaf always turns its upper side towards the sky so that it may be better able to receive over its whole surface the dew which drops down with the slow movement of the atmosphere; and these leaves are arranged on the plants in such a way that one covers another as little as possible, but they lie alternately one above the other as is seen with the ivy which covers the walls. And this alternation serves two ends; that is in order to leave spaces so that the air and the sun may penetrate between them, — and the second purpose of it is that the drops which fall from the first leaf may fall on to the fourth, or on to the sixth in the case of other trees.

G 27 v.

[*Structure of the walnut tree*]

The leaves of the walnut tree are distributed over the whole branch of that year, and they are so much farther away the one from the other, and in greater number, as the branch from which the shoot springs is younger. And they are so much nearer at their beginning and less in number, as the shoot that bears them springs from an older branch.

Its fruits grow at the extremity of its shoot, and its largest branches are on the under side of the bough from which they spring. And this happens because the weight of its sap inclines it more to descend than to rise; and for this reason the branches that start above them and go toward the sky are small and thin. When the shoot looks towards the sky its leaves spread out from its extremity with equal distribution of their tips, and if the shoot looks towards the horizon the leaves remain

VIOLAS

Institut de France MS. B. 14. r

spread out; this springs from the fact that the leaves invariably turn their underneath side towards the ground.

The branches are proportionately smaller as they start nearer to the birth of the bough which produces them.

G 28 r.

[*The elder*]

Observe on the lower branch of the elder which has its leaves in twos placing them crosswise one above the other, if the stem goes straight up towards the sky this order never fails, and its larger leaves occur on the thicker part of the stem and the smaller on the thinner part that is towards the top. But to come back to the branch below, I maintain that the leaves which are placed crosswise to those on the upper branch, being constrained by the law which causes the leaves to turn part of their surface towards the sky in order to catch the dew at night, must necessarily twist round when so placed and be no longer crosswise.

G 29 r.

OF THE RAMIFICATIONS OF TREES WITH THEIR LEAVES

Of the ramifications of trees some such as the elm are wide and thin after the fashion of a hand open foreshortened, and these are visible in their whole mass. Below they are seen in their upper side, and those that are highest are seen from beneath; those of the centre show themselves part below and part above, and the part above is at the end of the ramification; and this part that is in the centre is more foreshortened than any other of those which are turned with their points towards you. Of these parts that are in the centre of the height of the tree the longest will be towards the extremities of these trees; and these make ramifications like the leaves of the common willow which grows upon the banks of rivers.

Other ramifications are round, such as those of the trees that put forth their shoots and leaves so that the sixth is above the first. Others are thin and diaphanous as the willow and such like trees.

G 30 v.

OF THE BEGINNING OF THE BRANCHES IN TREES

The beginning of the ramifications of trees upon their principal branches is the same as the beginning of the leaves upon the shoots of the same year as the leaves. And these leaves have three ways of proceeding one higher than the other; the first and most usual is that the

sixth on the upper side always is born above the sixth on the under side; the second is that the two thirds above are over the two thirds below; and the third way is that the third above is over the third below.

WHY FREQUENTLY THE VEINS OF WOOD ARE NOT STRAIGHT

When the branches which follow the second year above that of the previous year are not of equal thickness above the preceding branches but are one-sided, the strength of the branch below is bent to nourish that which is higher although it is somewhat on one side.

But if such ramifications are equal in their growth, the veins of their branch will be straight, and at an equal distance at every stage of the height of the plant.

Do you therefore O painter who are not acquainted with these laws, if you would escape the censure of those who have studied them, be zealous to represent everything according to nature and not to disparage such study, as do those who work only for gain.

G 33 r.

Every branch and every fruit comes above the insertion of its leaf, which serves it as a mother by bringing it the water of the rains and the moisture of the dew that falls there at night from above, and often takes from them the excessive heat of the sun's rays.

G 33 v.

There is no protuberance on a branch except where there has been some branch which has failed.

The lower shoots of the branches of trees increase more than the upper shoots, and this simply arises from the fact that the sap which feeds them having gravity moves downwards more readily than upwards. And also because those which grow downwards separate themselves from the shade which there is in the centre of the tree.

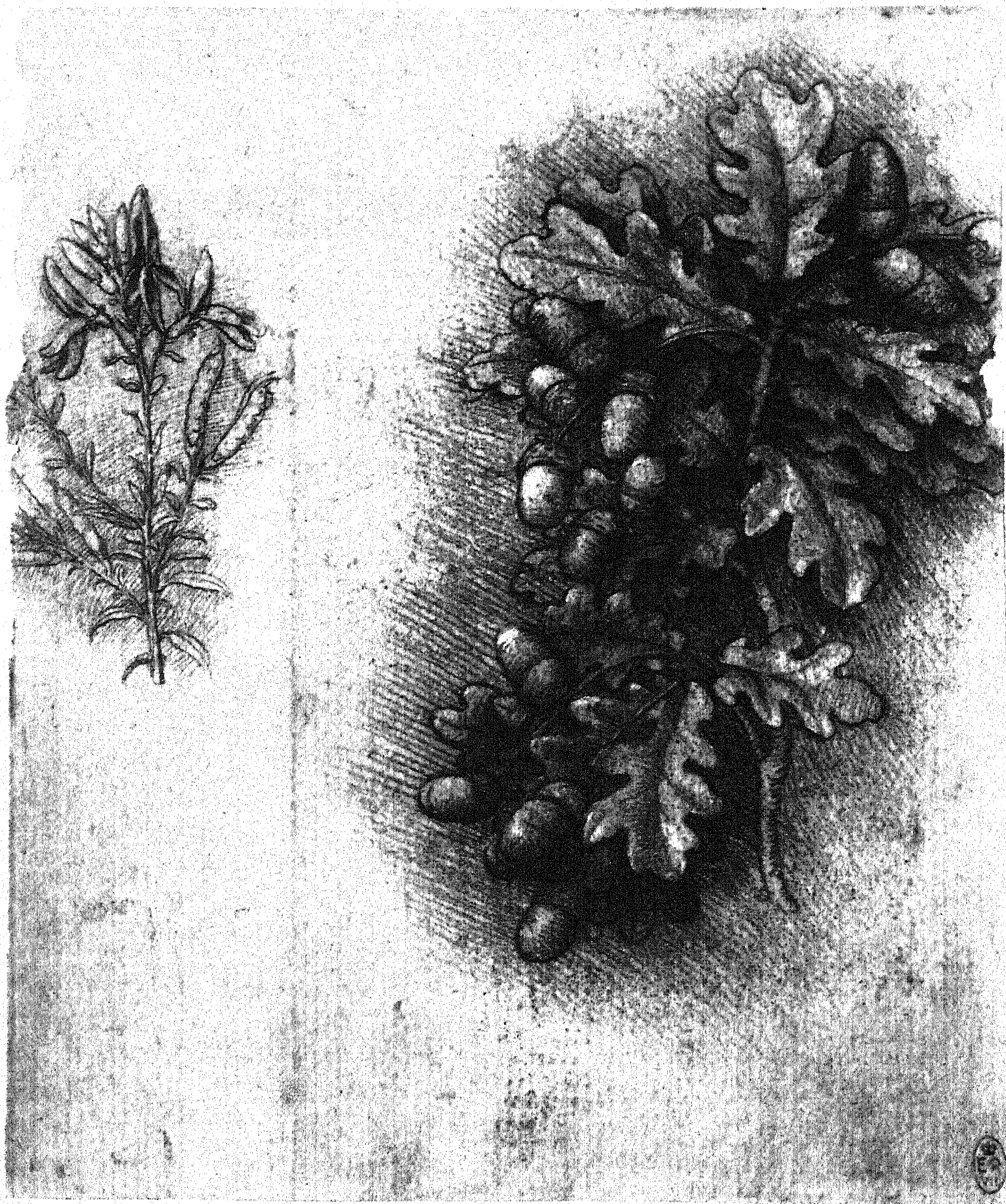
The older the branches the greater the difference will be between their upper and lower shoots and between those of the same year or period.

G 34 v.

OF THE CICATRICES OF TREES

The cicatrices of trees grow in thickness more than the sap that flows through them and nourishes them requires.

G 35 r.



DYER'S GREENWEED, OAK LEAVES AND ACORNS

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The lower branches after they have formed the angle of their separation from their trunk always bend down, so as not to press against the other branches which follow above them on the same trunk and to be better able to take the air which nourishes them.

G 35 V.

The elm always puts greater length into the latest branches of the year's growth than it does into those of the same year which are lower. Nature does this because the higher branches are those which are to increase the size of the tree; while those below tend to dry up because they remain in the shadow, and their growth would be a check to the entry of the solar rays and the air among the chief branches of the tree.

The chief of the lower branches bend down more than the upper ones both in order to be more slanting than the upper ones and also because they are larger and older; and in order to seek the air and escape from the shade.

G 36 r.

[*Branch structure and the sun*]

Universally almost all the upright parts of trees are found to bend somewhat turning their convex part towards the south. And the branches are longer thicker and more numerous towards the south than towards the north. This arises from the fact that the sun draws the sap towards that part of the surface of the tree which is nearest to it. This is evident in the trees which are frequently pollarded, for they renew their growth every three years. And one notices this unless the sun is screened off by other trees.

G 36 V.

All the flowers which see the sun mature their seed, and not the others, that is those which see only the reflection of the sun.

G 37 V.

The cherry is of the same nature as the fir in that its ramification is made in steps round its stem; and its branches grow in fours fives or sixes opposite one another; and the sum of the extremities of the branches forms an equilateral pyramid from its centre upwards; and the walnut and the oak from the centre upwards form a half sphere.

G 51 r.

[*Symmetry of nature — ramifications of trees and water*]

All the branches of trees at every stage of their height, united together, are equal to the thickness of their trunk.

All the ramifications of the waters at every stage of their length being of equal movement are equal to the size of their parent stream.

I 12 v.

[*Laws as to growth of plants*]

Every year when the branches of the trees have completed their growth, they have attained when joined together to such thickness as the thickness of their trunk, and at each stage of their ramification you will find the thickness of the said trunk as in *ik*, *gh*, *ef*, *cd*, *ab*. They will all be equal to each other if the tree has not been pollarded; otherwise the rule will not fail.

M 78 v.

If the plant *n* grows to the thickness of *m* its branches will make the whole conjunction *ab* through the swelling of the branches within as well as outside.

The branches of plants form a curve at every commencement of a tiny branch, and as this other branch is produced they bifurcate, and this bifurcation occurs in the middle of two angles the greater of which will be that on the side of the thicker branch, and this will be in proportion unless some accident has marred it.

M 79 r.

All the branches produced towards the centre of the tree wither and fall on account of the excess of shade; only such part of the system of ramification endures as lies in the extremities of the tree.

B.M. 180 v.

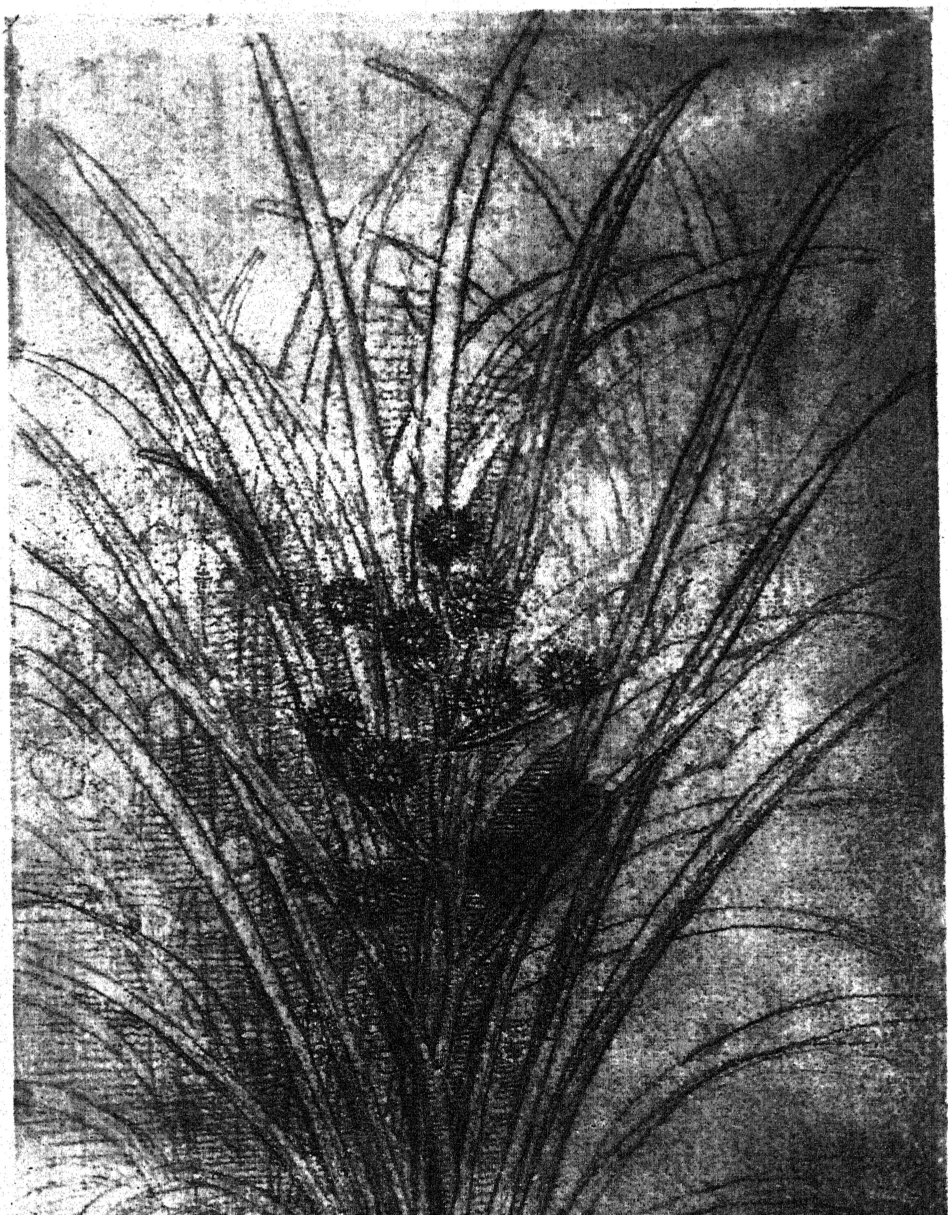
[*Unity in nature — all seeds have the umbilical cord*]

All seeds have the umbilical cord, which breaks when the seed is ripe. And in like manner they have matrix and secundina, as is seen in herbs and all the seeds which grow in pods. But those which grow in shells, such as hazel-nuts, pistachio-nuts and the like have the umbilical cord long, and this shows itself in their infancy.

Quaderni III 9 v.

A discourse concerning the herbs some of which have the first flower placed at the very top of the stalk, others have it at the bottom.

Quaderni IV 15 r.



FLOWERING RUSHES
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XIII

Geology

'When nature is on the point of creating stones it produces a kind of sticky paste, which, as it dries, forms itself into a solid mass together with whatever it has enclosed there, which, however, it does not change into stone but preserves within itself in the form in which it has found them.'

The lying interpreters of nature assert that mercury is a common factor in all the metals; they forget that nature varies its factors according to the variety of the things which it desires to produce in the world.

C.A. 76 V. a

The streams of rivers move different kinds of matter which are of varying degrees of gravity, and they are moved farther from their position in proportion as they are lighter, and will remain nearer to the bottom in proportion as they are heavier, and will be carried a greater distance when driven by water of greater power.

But when this power ceases to be capable of subduing the resistance of the gravel this gravel becomes firm and checks the direct movement of the water which led it to this place. Then the water, as it strikes on the gravel which has been increased in this manner, leaps back crosswise and strikes upon other spots to which it was unaccustomed, and takes away other deposits of soil down to their foundations. And so the places where first the said river used to pass are deserted and become silted up anew by a fresh deposit from the turbid waters, and these in due course become choked up in these same places.

C.A. 77 V. b

Of the rivers greatly swollen by the falling down of the mountains along their sides which bring about the formation of very great lakes at high altitudes:

The avalanches from the mountains falling down upon their bases which have been worn away by the continuous currents of the rivers rushing precipitously at their feet with their swift waters, have closed up the mouths of the great valleys situated in the high places.

These are the causes why the surface of the water is raised by the creation of lakes, and why new streams and rivers are formed in high places.

C.A. 84 r. a

The ebb and flow of the sea is continually moving the earth with all its elements away from the centre of the elements. This is proved by the first [chapter] of this [treatise], which states that the centre of the world takes count of that which is higher than it because no hollow lies deeper than it. The centre of the world is in itself immovable, but the place in which it is found is in continual movement towards different aspects.

The centre of the world changes its position continually, and of these changes some have a slower movement than the others, for some changes occur every six hours and some take many thousand years.

But that of six hours proceeds from the ebb and flow of the sea, the other comes from the wearing away of the mountains through the movements of the water produced by the rains and the continual course of the rivers. The site changes in its relation to the centre of the world and not the centre to the site, because this centre is immovable and its site is continually moving in a rectilinear movement, and such movement will never be curvilinear.

C.A. 102 r. b

The rains wear away more of the roots of the mountains than they do the summits for two reasons; and the first is that the percussion of the rain in falling from the same height is more powerful on the bases of the mountains than on their summits by my seventh [rule], which says that a heavy thing becomes so much swifter as it descends farther in the air, and as it becomes swifter so it becomes heavier. As therefore there is more space between the roots of the mountains and the cloud than between these clouds and the summit of the mountain, the rain, as has been said, is heavier and more powerful upon these roots of the mountains than on the summit of the same mountain, and so stage by stage its power to wear away is less as it has a less fall.

The second reason is that the greater mass of water is that which descends from the centre of the mountain to its roots rather than from the summit of this mountain to the said centre; and so we have discharged our purpose.

Valleys grow wider with the progress of time: their depth undergoes but little increase; because the rains bring as much soil to the valley almost as the river washes away, and in some parts more in others less.

Very great rivers flow underground.

The rivers make greater deposits of soil when near to populated districts than they do where there are no inhabitants. Because in such places the mountains and hills are being worked upon, and the rains wash away the soil that has been turned up more easily than the hard ground which is covered with weeds.

STRATIFIED ROCKS

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The heights of mountains are more eternal and more enduring when they are covered with snow during the whole winter. C.A. 160 V. a

In between water and stone in equal quantities are an almost infinite number of different grades of weight, that is there are as many varieties of the weights as there are of the thicknesses; so there will be pure water, then water with a very small quantity of earth in it, and then this is increased little by little until it forms mud, and then this mud becomes more solid, and at last it becomes solid earth, and then goes on to become like the hardest stone and is even transformed into the metals.

And this I say because I have to take away like things in order to press the water out of its vessels.

Of the rising of the water to the mountains, which acts like water that rises up through the plants from the roots to the summits, as is seen in vines when they are cut; and as the blood works in all the animals so water does in the world, which is a living body. C.A. 367 V. b

If the earth of the antipodes which sustains the ocean rose up and stood uncovered far out of this sea but being almost flat, how in process of time could mountains valleys and rocks with their different strata be created?

The mud or sand from which the water drains off when they are left uncovered after the floods of the rivers supplies an answer to this question.

The water which drained away from the land which the sea left, at the time when this earth raised itself up some distance above the sea, still remaining almost flat, commenced to make various channels through the lower parts of this plain, and beginning thus to hollow it out they would make a bed for the other waters round about; and in this way throughout the whole of their course they gained breadth and depth, their waters constantly increasing until all this water was drained away and these hollows became then the beds of torrents which take the floods of the rains. And so they will go on wearing away the sides of these rivers until the intervening banks become precipitous crags; and after the water has thus been drained away these hills commence to dry and to form stone in layers more or less thick according to the depth of the mud which the rivers deposited in the sea in their floods. F II V.

Of creatures which have their bones on the outside, like cockles, snails, oysters, scallops, 'bouoli' and the like, which are of innumerable kinds:

When the floods of the rivers which were turbid with fine mud deposited this upon the creatures which dwelt beneath the waters near the ocean borders, these creatures became embedded in this mud, and finding themselves entirely covered under a great weight of mud they were forced to perish for lack of a supply of the creatures on which they were accustomed to feed.

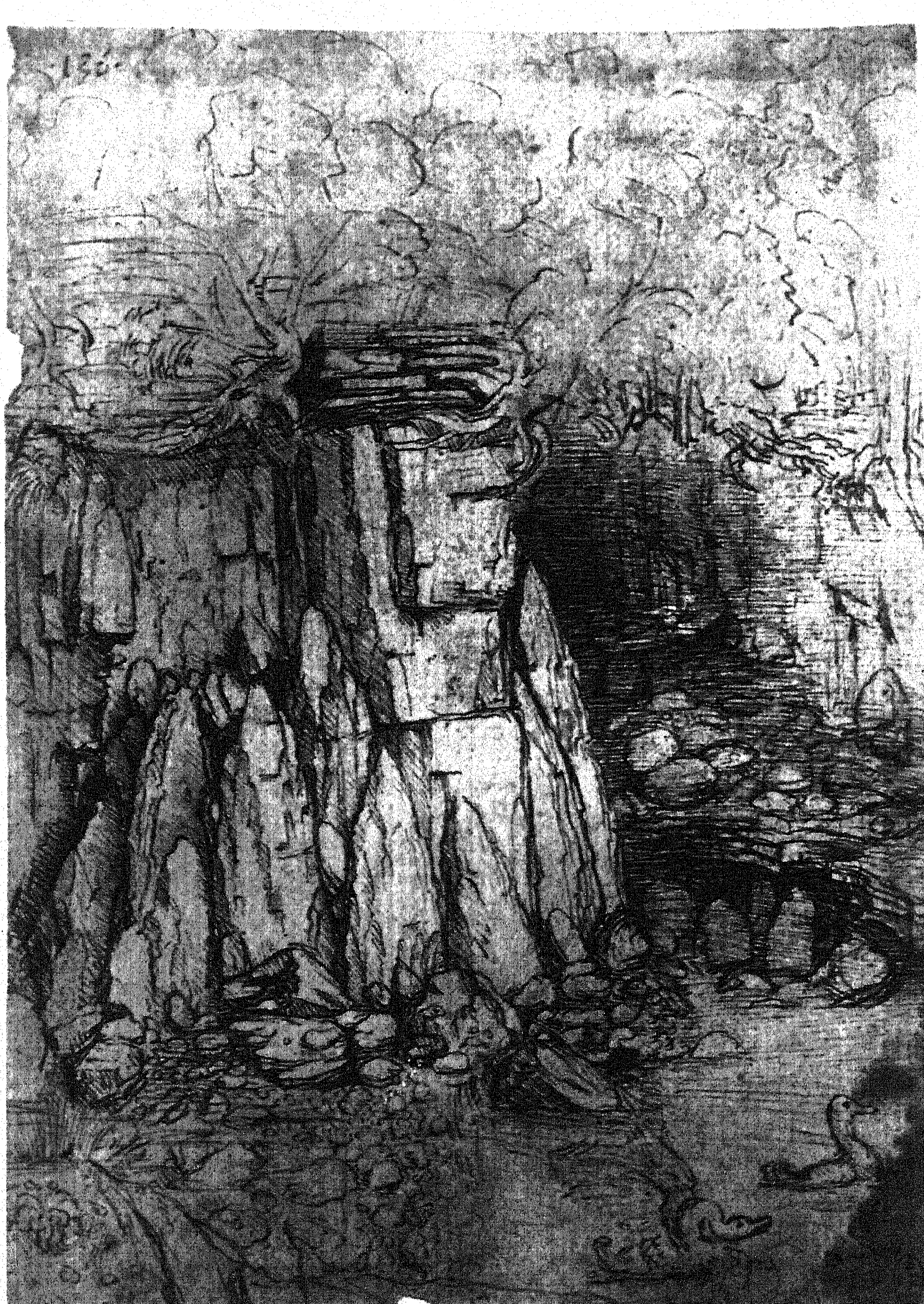
In course of time the level of the sea became lower, and as the salt water flowed away this mud became changed into stone; and such of these shells as had lost their inhabitants became filled up in their stead with mud; and consequently during the process of change of all the surrounding mud into stone, this mud also which was within the frames of the half-opened shells, since by the opening of the shell it was joined to the rest of the mud, became also itself changed into stone; and therefore all the frames of these shells were left between two petrified substances, namely that which surrounded them and that which they enclosed.

These are still to be found in many places, and almost all the petrified shellfish in the rocks of the mountains still have their natural frame round them, and especially those which were of a sufficient age to be preserved by reason of their hardness, while the younger ones which were already in great part changed into chalk were penetrated by the viscous and petrifying moisture.

F 79 r.

OF THE BONES OF FISHES FOUND IN THOSE THAT HAVE BEEN PETRIFIED

All the creatures that have their bones within their skin, on being covered over by the mud from the inundations of rivers which have left their accustomed beds, are at once enclosed in a mould by this mud. And so in course of time as the channels of the rivers become lower these creatures being embedded and shut in within the mud, and the flesh and organs being worn away and only the bones remaining, and even these having lost their natural order of arrangement, they have fallen down into the base of the mould which has been formed by their impress; and as the mud becomes lifted above the level of the stream, the mud runs away so that it dries and becomes first a sticky paste and then



ROCKY RAVINE WITH STREAM

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changes into stone, enclosing whatsoever it finds within itself and itself filling up every cavity; and finding the hollow part of the mould formed by these creatures it percolates gradually through the tiny crevices in the earth through which the air that is within escapes away — that is laterally, for it cannot escape upwards since there the crevices are filled up by the moisture descending into the cavity, nor can it escape downwards because the moisture which has already fallen has closed up the crevices. There remain the openings at the side, whence this air, condensed and pressed down upon by the moisture which descends, escapes with the same slow rate of progress as that of the moisture which descends there; and this paste as it dries becomes stone, which is devoid of weight, and preserves the exact shapes of the creatures which have there made the mould, and encloses their bones within it. F 79 V.

SHELLS AND THE REASON OF THEIR SHAPE

The creature that resides within the shell constructs its dwelling with joints and seams and roofing and the other various parts, just as man does in the house in which he dwells; and this creature expands the house and roof gradually in proportion as its body increases and as it is attached to the sides of these shells.

Consequently the brightness and smoothness which these shells possess on the inner side is somewhat dulled at the point where they are attached to the creature that dwells there, and the hollow of it is roughened, ready to receive the knitting together of the muscles by means of which the creature draws itself in when it wishes to shut itself up within its house.

When nature is on the point of creating stones it produces a kind of sticky paste, which as it dries, forms itself into a solid mass together with whatever it has enclosed there, which, however, it does not change into stone but preserves within itself in the form in which it has found them. This is why leaves are found whole within the rocks which are formed at the bases of the mountains, together with a mixture of different kinds of things, just as they have been left there by the floods from the rivers which have occurred in the autumn seasons; and there the mud caused by the successive inundations has covered them over, and then this mud grows into one mass together with the aforesaid paste, and becomes changed into successive layers of stone which correspond with the layers of the mud. F. 80 r.

OF SHELLS IN MOUNTAINS

And if you wish to say that the shells are produced by nature in these mountains by means of the influence of the stars, in what way will you show that this influence produces in the very same place shells of various sizes and varying in age, and of different kinds?

SHINGLE

And how will you explain to me the fact of the shingle being all stuck together and lying in layers at different altitudes upon the high mountains? For there there is to be found shingle from divers parts carried from various countries to the same spot by the rivers in their course; and this shingle is nothing but pieces of stone which have lost their sharp edges from having been rolled over and over for a long time, and from the various blows and falls which they have met with during the passage of the waters which have brought them to this spot.

LEAVES

And how will you account for the very great number of different kinds of leaves embedded in the high rocks of these mountains, and for the *aliga*, the seaweed, which is found lying intermingled with the shells and the sand?

And in the same way you will see all kinds of petrified things together with ocean crabs, broken in pieces and separated and mixed with their shells.

F 80 V.

In every hollow at the summits of the mountains you will always find the folds of the strata of the rocks.

B.M. 30 V.

XIV

Physical Geography

'The earth wears away the mountains and fills up the valleys and if it had the power it would reduce the earth to a perfect sphere.'

The wave travels beneath the surface[1] of the sea, and leaves behind itself all the foam which is produced in front of it.

The space of the surface of the water that intervenes between the waves as they come to the shore is polished and smooth; and this comes about because the greatest wave is swifter than the lesser waves of which it is made up [in the univer]sal surface of the sea; and this greatest wave draws back the surface of the sea, and the first foam of the wave descends as it opens at the spot where the remainder is fleeing away.

And the figure of the foam which then remains behind in the wave is always triangular, and its angle is made up of the first foam and that in front of the course where the wave first descended.

C.A. 63 r. b

The lowest parts of the world are the seas where all the rivers run.

The river never ceases its movement until it reaches the sea; the sea therefore is the lowest part of the world.

Water does not move from place to place unless it is drawn by a lower position. Lowness therefore serves as a magnet for water.

C.A. 80 r. b

Make a sketch to show where the shells are at Monte Mario.

C.A. 92 v. c

OF THE SEA WHICH GIRDLES THE EARTH

I perceive that the surface of the earth was from of old entirely filled up and covered over in its level plains by the salt waters, and that the mountains, the bones of the earth, with their wide bases, penetrated and towered up amid the air, covered over and clad with much high-lying soil. Subsequently the incessant rains have caused the rivers to increase and by repeated washing have stripped bare part of the lofty summits of these mountains, leaving the site of the earth, so that the rock finds itself exposed to the air, and the earth has departed from these places. And the earth from off the slopes and the lofty summits of the mountains has already descended to their bases, and has raised the floors of the seas which encircle these bases, and caused the plain to be uncovered, and in some parts has driven away the seas from there over a great distance.

C.A. 126 v. b

[1] *la pelle*, literally 'the skin' of the sea.

DOUBT

Here a doubt arises, and that is as to whether the Flood which came in the time of Noah was universal or not, and this would seem not to have been the case for the reasons which will now be given. We have it in the Bible that the said Flood was caused by forty days and forty nights of continuous and universal rain, and that this rain rose ten cubits above the highest mountain in the world. But consequently if it had been the case that the rain was universal it would have formed in itself a covering around our globe which is spherical in shape; and a sphere has every part of its circumference equally distant from its centre, and therefore on the sphere of water finding itself in the aforesaid condition, it becomes impossible for the water on its surface to move, since water does not move of its own accord unless to descend. How then did the waters of so great a Flood depart if it is proved that they had no power of motion? If it departed, how did it move, unless it went upwards? At this point natural causes fail us, and therefore in order to resolve such a doubt we must needs either call in a miracle to our aid or else say that all this water was evaporated by the heat of the sun.

C.A. 155 r. b

[*Diagram*]

Three is the number of the winds which bend the rivers to the west as they discharge themselves into the Mediterranean Sea on the shores that face south. This is proved as follows: the sand that is driven by the winds into the water is no longer subject to the winds, through being weighed down by the water which covers it over and forms a screen for it against these winds.

Therefore the river *n m* which flows into the sea will half way in its course make a beginning of a movement to the west, when it feels the breath of the winds known as Greco, Levante and Scirocco, which at various times set the dry sand of the shore spinning, and hurl it into the sea, where it becomes submerged and settles upon the bed of the sea. But the north wind called Greco throws it to the south-west, and the Scirocco throws it to the north-west. But the southern waves striking on the shore throw this sand back towards the river, and the river strikes it back towards the sea; and when the waves struck back from the shore come to an encounter with the waves advancing to the shore the movement of these waves then ceases because the power of their movement is lacking. Therefore the sand having made the water turbid descends to

ALPINE VALLEY WITH TOWN

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the bottom, and it is this same sand which forms itself into a bank and bends in a westerly direction the aforesaid river. Why does it not bend the course of the river to the east as well as to the west? Because the sea has been proved to run to the west and not to the east.

Let us therefore make a bridge as wide and low as the shore out of large planks.

C.A. 167 v. a

The water wears away the mountains and fills up the valleys, and if it had the power it would reduce the earth to a perfect sphere.

C.A. 185 v. c

INSTANCES AND DEDUCTIONS AS TO THE EARTH'S INCREASE

Take a vase, fill it full of pure earth, and set it up on a roof. You will see how immediately the green herbs will begin to shoot up, and how these, when fully grown, will cast their various seeds; and after the children have thus fallen at the feet of their parents, you will see the herbs having cast their seeds, becoming withered and falling back again to the earth, and within a short time becoming changed into the earth's substance and giving it increase; after this you will see the seeds springing up and passing through the same course, and so you will always see the successive generations after completing their natural course, by their death and corruption giving increase to the earth. And if you let ten years elapse and then measure the increase in the soil, you will be able to discover how much the earth in general has increased, and then by multiplying you will see how great has been the increase of the earth in the world during a thousand years. Some may say that this instance of the vase which I have mentioned does not justify the deduction based upon it, because one sees in the case of these vases that for the prize of the flowers that are looked for a part of the soil is frequently taken away, and its place is filled up with new rich soil; and I reply to them that as the soil which is added there is a blend of rich fat substances and broken bits of all sorts of things it cannot be said to be pure earth, and this mass of substances decaying and so losing in part their shape becomes changed into a rich ooze, which feeds the roots of the plants above them; and this is the reason why it may appear to you that the earth is lessened; but if you allow the plants that grow in it to die, and their seeds to spring up, then in time you will behold its increase.

For do you not perceive how, among the high mountains, the walls

of ancient and ruined cities are being covered over and concealed by the earth's increase?

Nay, have you not seen how on the rocky summits of the mountains the live stone itself has in course of time swallowed up by its growth some column which it supported, and stripping it bare as with shears and grasping it tightly, has left the impress of its fluted form in the living rock?

C.A. 265 r. a

When mountains fall headlong over hollow places they shut in the air within their caverns, and this air, in order to escape, breaks through the earth, and so produces earthquakes.

My opponent says this cannot be the case, for either the whole mountain which covers the cavern falls or else only the inner part of it; and if the whole falls, then the compressed air escapes through the opening of the cave which is uncovered, while if only the inner part falls then the compressed air escapes into the vacuum which is left by the falling earth.

C.A. 289 v. b

Similarly the movements of the waters running through all the passages of the sterile earth are its life-giving force. And just as the moisture spread through the vine rises up and pours through the severed members, (the utmost heights of the mountains through the severed veins), so it is with the water which rises to a height and pours through the chasms in the topmost heights of the mountains.

In the same way the waters from the base rise to a height, pouring through the chasms in the topmost heights of the highest mountains.

And as the moisture which pours through the severed vine desires only the centre of the earth and moves towards it, so the waters pouring from the heights of the mountains move of their own free will towards this centre.

And as the water from the severed vine falling down upon its roots and penetrating into these raises itself up to a height and pours itself out again at the very place where the cutting was, so the water falling from the summits of the mountains and penetrating through the passages of the earth returns upwards.

C.A. 309 v. a

The surface of the Red Sea is on a level with the Ocean.

This made the Mediterranean light both in the bed which is lowered and in the surface where formerly was the water.

Lacking the weight of the waters of the Mediterranean which had been diminished the earth rose and changed in itself its centre of gravity.

The waters of the sea which descend into the Ocean from the Mediterranean Sea have through the force of their impact on the bottom hollowed out this bed considerably beneath the surface of this Ocean; and in their fall this hollowing out has withdrawn itself to the point at which it arrives at the end of the channel of Gades, and there it is visible to-day.

A mountain may have fallen and blocked the mouth of the Red Sea and prevented the outlet to the Mediterranean, and thus swirling in a flood this sea will have as its outlet the passage between the mountains of Gades, for in the same way we have seen in our time a mountain fall seven miles and block up a valley and make a lake; and thus the greater number of the lakes were made by mountains, as the lake of Garda, of Como and Lugano and Lake Maggiore. . . .

All the plains which lie between the seas and the mountains were once covered by the salt waters.

Every valley has been made by its river, and the proportion between valleys is the same as that between rivers.

The greatest river in the world is the Mediterranean which is a river that moves from the source of the Nile to the Western Ocean.

C.A. 328 v. b

The water given to the Mediterranean by rain and rivers is restored to the Ocean through the straits of Gades [Gibraltar], with so much less water in proportion as the springs are beneficent to it and the sea evaporates it.

And this excess is the cause of the ebb and flow, because in the flow the Mediterranean is swollen up by the Ocean and this turns back and ebbs away through the Mediterranean which discharges it. C.A. 353 v. c

Just as the snow as it falls in flakes upon various rounded objects covers them with itself but with as many varying degrees of thickness as there are variations in the curves of this roundness, so the earth, borne by the floods of the rivers after the mass of the waters, descends upon the various rounded objects which are at the bottom of the waters and covers these with itself in the manner shown above.

C.A. 383 v.

OF THE CENTRE OF THE OCEAN

The centre of the sphere of water is the true centre of the orb of our world which is compounded of land and water in the shape of a sphere.

But if you wish to find the centre of the element of the earth this is situated at a point equidistant from the surface of the ocean and not equidistant from the surface of the earth. For it is easy to understand that this globe of the earth has no perfect roundness whatever except in those parts in which are the sea or lakes or other surfaces of still water; and every part of the land which rises above the water is farther removed from the centre.

A 58 V.

OF THE MOVEMENT OF AIR AND WATER

This air which bounds and continually moves upon this terrestrial machine is mixed with moisture similar to that with which the earth is compounded, and the excess of this moisture falls back continually upon the earth once in twenty-four hours and then springs back raised a little by the heat of the sun and sustained by it so long as it remains in our hemisphere. Then being left abandoned by it at its departure and still having weight it falls back on the earth.

In summer this moisture is called dew and in winter as the cold condenses it and freezes it it is called hoar frost.

C 6 R.

OF HOW THE SEA CHANGES THE WEIGHT OF THE EARTH

The shells of oysters and other similar creatures which are born in the mud of the sea testify to us of the change in the earth round the centre of our elements. This is proved as follows: — the mighty rivers always flow turbid because of the earth stirred up in them through the friction of their waters upon their bed and against the banks; and this process of destruction uncovers the tops of the ridges formed by the layers of these shells, which are embedded in the mud of the sea where they were born when the salt waters covered them. And these same ridges were from time to time covered over by varying thicknesses of mud which had been brought down to the sea by the rivers in floods of varying magnitude; and in this way these shells remained walled up and dead beneath this mud, which became raised to such a height that the bed of the sea emerged into the air.

And now these beds are of so great a height that they have become hills or lofty mountains, and the rivers which wear away the sides of these mountains lay bare the strata of the shells, and so the light surface of the earth is continually raised, and the antipodes draw nearer to the

centre of the earth, and the ancient beds of the sea become chains of mountains.

E 4 v.

The destruction of marshes will be brought about when turbid rivers flow into them.

This is proved by the fact that where the river flows swiftly it washes away the soil, and where it delays there it leaves its deposit, and both for this reason and because water never travels so slowly in rivers as it does in the marshes of the valleys the movement of the waters there is imperceptible. But in these marshes the river has to enter through a long narrow winding channel, and it has to flow out over a large area of but little depth; and this is necessary because the water flowing in the river is thicker and more laden with earth in the lower than in the upper part; and the sluggish water of the marshes also is the same, but the variation between the lightness and heaviness of the upper and lower waters of the marshes far exceeds that in the currents of the rivers, in which the lightness of the upper part differs but little from the heaviness of the part below.

So the conclusion is that the marsh will be destroyed because it is receiving turbid water below, while above, on the opposite side of the same marsh, only clear water is flowing out; and consequently the bed of the marsh will of necessity be raised by means of the soil which is being continually discharged into it.

E 5 r.

How by running waters one should conduct the soil of the mountains into marshy valleys and so render them fertile and purify the surrounding air:

The ramifications of the canals which are led from the high hills according to their natural course are those which in their changes carry the soil from these hills to the low marshes, filling them up with earth and rendering them fertile.

Let *a* be the main stream which enters the marshes at *b f s*; let the canal start from the height of the hills *a c n*, from which suppose various branches to have fallen, changing it where it is all united into different places, and thus their fury tears away the soil and after they have run their course they deposit it in the low swamps; and thus you will be able to change so much the fall of the whole canal, abounding as it does in water, that you will have levelled the soil left uncovered from these marshes.

F 14 r.

Why pools are formed near the sea, and why their great floods are poured into the sea through so narrow a channel, upon the sides of which between the pool and the sea so great a bank is formed:

The storms of the sea cast up on to the shore a great quantity of sand, and this is heaped up all along the shore both at the mouth of the pool and elsewhere; and as the storm ceases the mouth of the pool remains closed by the aforesaid matter thrown up by the sea. And as the water that the pool receives from the neighbouring rivers cannot find any other exit it proceeds to rise and acquire weight and power; and therefore it either bursts through the bank interposed between it and the sea or flows over it and with its outpouring wears away as much of the bank as it touches, pursuing its course until it has cleared out of its path all the matter that impeded its necessary dispersion.

Moreover it only consumes what is necessary; at first it is very large because the water that flows towards where the mouth should be is clear, and at the end the course of the water becomes contracted, because it has become thicker as it acquires depth; and this is the reason why such outlet from the pools to the sea is always narrow.

F 40 v.

OF THE WAVES

Sometimes the waves are swifter than the wind, and sometimes the wind is much swifter than the wave; the ships prove this upon the sea. The waves can be swifter than the wind through having been commenced by the great winds, the wind then having ceased and the wave having still preserved a great impetus.

F 48 v.

One asks whether a river which passes through a lake changes the uniform distance at which the surface of this lake was from the centre of the earth before this river passed through the said lake.

This is an interesting question; and one shows that this surface disturbs the uniformity of its distance from the centre of the earth in order to give a passage to the said river, by the fourth [rule], which shows that water does not move unless to descend. And here it is necessary to understand whether the exit of the river has a width equal to that of the entrance and if this is so it is necessary that the water be of uniform course, by the seventh [rule], which shows that the movement of every river in an equal time gives to every part of its length an equal weight of water. Now if the river emitted water which required a drop of a

braccio in a mile, the width of the exit being as has been said equal to the width of the entrance, it would be necessary that all the river which passes through the lake should also have a drop of one braccio per mile, and consequently the water of this lake would have its surface at a varying distance from the centre of the earth. But the water will have this course. . . .

That part of the water of the lake will be of slowest movement which finds itself farthest removed from the shortest line from the entrance to the exit of the river which passes through this lake.

Here it follows that the Sea of Azov which borders upon the Don is the highest part of the Mediterranean Sea; and it is three thousand five hundred miles distant from the straits of Gibraltar, as is shown by the navigators' chart; and it has a descent of three thousand five hundred braccia, that is a mile and a sixth, this sea consequently being higher than any mountain that there is in the west.

F 68 r. and v.

OF THE WIND

Since the eddies of the winds are below and above as well as crosswise the countryfolk cannot tell what wind it is that is blowing, that is those who dwell under the hills by the sea shores do not know if the wind is from an eddy or if it is the straight wind.

The wind that strikes upon the sea coasts or borders or sides of the mountains raises itself up to the summit where it presses itself against the course of the other straight wind, and then it spreads itself out moistening the opposite. . . .

I 130 [82] v.

Why the thunder lasts for a longer time than that which causes it; and why, immediately on its creation, the lightning becomes visible to the eye, while the thunder requires time to travel, after the manner of a wave, and makes the loudest noise when it meets with most resistance.

K 110 [30] v.

WINDS AND THUNDERBOLTS

The winds which rise from the cloud continue in movement; in such a way that the more they move the farther they rise in the lighter air because they are less impeded there. And if they meet each other they leap back, and it is in these encounters that thunderbolts are produced.

If the wind originates at a low altitude, what is it that drives it more to the east than to the west?

K 113 [33] r.

[*Watery sphere and centre of world*]

The surface of the watery sphere is always more remote from the centre of the world:

This comes about by reason of the soil brought by the inundations of turbid rivers. These deposit the soil which causes their turbidity on the shores of the ocean and so narrow the sea beach; beside this they raise their bed and so of necessity the surface of this element comes to be raised.

The centre of the world continually changes its position in the body of the earth fleeing towards our hemisphere.

This is shown by the above-mentioned soil which is continually carried away from the declivities or sides of the mountains and borne to the seas; the more it is carried away from there the more it becomes lightened and as a consequence the more it becomes heavy where this soil is deposited by the ocean waves, wherefore it is necessary that such centre changes its position.

L 13 v.

[*Surface of the earth and centre of gravity*]

That part of the surface of any heavy body will become more distant from the centre of its gravity which becomes of greater lightness.

The earth therefore, the element by which the rivers carry away the slopes of the mountains and bear them to the sea, is the place from which such gravity is removed; it will make itself lighter and in consequence will make itself more remote from the centre of the gravity of the earth, that is from the centre of the universe which is always concentric with the centre of the gravity of the earth.

L 17 r.

[*Changes in mountains and valleys*]

The summits of the mountains in course of time rise continually.

The opposite sides of the mountains always approach one another.

The depths of the valleys which are above the watery sphere in course of time constantly draw near to the centre of the world.

During the same period of time the valleys sink much more than the mountains rise.

The bases of the mountains are always drawing closer together.

As the valley grows deeper so its sides become worn away in a shorter space of time.

L 76 r.

[*Cosmography of Ptolemy*]

A line commenced at one extremity of the world may still be parallel and equidistant to another line commenced at the opposite side of the world, as Ptolemy shows in his Cosmography when he shows that cities situated in the opposite extremities of the earth are in the same parallel.

M 5 V.

[*Water upon sand*]

Why as smooth sand is formed of grains uneven in shape and size the water which flows above them drives these grains with varying degrees of movement? Just as the bodies that vary in weight and shape make different movements in the still air so do the air and the water as they move among still bodies. And this is why the sand loses its smoothness by the movement of the water that passes over it. And the moved water performs the same function upon the sand as the moved air does upon the water. And if you prove that the bed of the flat sand makes its waves and becomes uneven through the unevenness of its granules, and that such unevenness could not exist on the surface of the water which is a smitten and uniform body, I will maintain that the air is full of parts which have a movement that is not uniform and therefore the parts moved by the contact of the air move without uniformity.

M 41 r.

The cause which makes water move in the springs contrary to the natural course of its gravity works in the same way in all the humours in all species of animated bodies. And just as the blood from below surges up and then falls back should a vein burst in the forehead, so the water rises from the lowest depth of the sea to the summits of the mountains, and there, finding the springs burst open, is poured out through them and returns to the depths of the sea. Have you ever seen how the water that drips from the severed branches of the vine and falls back upon its roots penetrates these and so rises up anew? Thus it is with the water that falls back into the sea, for it penetrates through the pores of the earth and having returned into the power of its mover, whence it rises anew with violence and descends in its accustomed course, it then returns. Thus adhering together and united in continual revolution it goes moving round backwards and forwards; at times it all rises together with fortuitous movement, at times descends in natural liberty. Thus moving up and down, backwards and forwards, it never rests in quiet either in its

course or in its own substance: and as the mirror is changed to the colour of the objects which pass before it, it has nothing of itself but moves or takes everything, and is changed to as many different natures as the places are different through which it passes.

B.M. 58 v.

That principle which moves the watery humours contrary to the natural course of their gravity in all living species moves the water also through the springs in the ground, and with continual solicitude renders aid in all those places in which necessity teaches it. And that which is seen falling down from high places and forming the commencement of the course of every river, acts in the same manner as the blood that rises up from the lower part and pours itself away through a cleft in the forehead.

B.M. 59 r.

From the two lines of shells one must needs suppose that the earth in disdain plunged beneath the sea and so formed the first layer and that the Flood afterwards formed the second.

B.M. 156 v.

How the rivers widen the valleys and wear away the roots of the mountains along their sides:

The windings which the rivers make through their valleys as they leap back from one mountain to another cause the bank to form curves, and these curves move with the current of the water and in course of time seek out the whole valley, unless they are checked by the fact of it becoming increased in length and depth and diminished in breadth.

B.M. 168 v.

And as from the lower part of the vine the water rises to the severed branches, and falls back upon its roots and by penetrating these rises up again to the point where they are broken and falls back afresh, even so does the water.

So from the lowest depth of the sea the water raises itself and rises to the summits of the mountains, and as the water pours through the severed branches of the vine and falls back upon its roots, penetrating them, even so does the water which. . . .

B.M. 233 r.

So does the water which is moved from the deep sea up to the summits of the mountains, and through the burst veins it falls down again to the shallows of the sea, and so rises again to the height where it burst

through, and then returns in the same descent. Thus proceeding alternately upwards and downwards at times it obeys its own desire at times that of the body in which it is pent.

B.M. 233 v.

Every heap of sand whether it be on level ground or sloping will have its base twice the length of its axis.

Forster II 16 r.

OF THE SEA

If the water becomes so salt through the earth being burnt up by the sun it should follow that when the earth is boiled in water this water becomes salt.

Quaderni II 19 r.

[*Influence of sun and moon on tides*]

That power shows itself greater which is impressed upon a lesser resistance. This conclusion is universal and we may apply it to the flow and ebb in order to prove that the sun or moon impresses itself more on its object, that is on the waters, when these are of less depth. Consequently the shallow waters of swamps ought to receive with greater potency the cause of the flow and ebb, than the great depths of the ocean.

Quaderni II 22 v.

[*Filling of footprints in sand*]

When the foot is drawn up out of wet sand the water runs back right to the surface of the sand, and this occurs because the water which is mingled with the sand is quicker to fill up the vacuum left by the foot than the sand is, and the air would be even quicker if it could enter; but the wet sand always keeps the way closed up by which the leg entered the sand, and so prevents the air from entering to fill up the vacuum.

Quaderni IV 15 r.

How the valleys were formerly in great part covered by lakes because their soil always forms a bank for rivers, and by seas which afterwards through the unceasing action of the rivers that form the store of water that is in the m[ountains], cut through the mountains; and the rivers in their wandering courses carried away the wide open plains enclosed by the mountains; and the cuttings of the mountains are perceptible from the strata of the rocks which correspond to the sections made by the said courses of the rivers:

The Haemus range which crosses Thrace and Dardania and joins on the west the Sardonius range as it proceeds towards the west changes the

name of Sardus to Rebi as it approaches Dalmatia, and then continuing towards the west crosses Illyria now called Slavonia, and changes the name of Rebi to Albanus, and still continuing westward changes it to the Ocra range.

To the north and south above Istria it is named Caruancas (Carusadius?), and to the west above Italy it unites with the Adula range where the Danube[1] rises, which flows for a course of fifteen hundred miles and for about a thousand miles in the most direct line; and for just as far or thereabouts the spur of the Adula range is changed to the names of the mountains already mentioned.

To the north stands the Carpathian range which encloses the breadth of the valley of the Danube which as I have stated stretches eastwards for a distance of about a thousand miles and has a width of sometimes two hundred and sometimes three hundred miles. Through the midst of it flows the Danube, the first river of Europe in magnitude, and this Danube as it flows leaves on the south Austria and Albania and on the north Bavaria, Poland, Hungary, Wallachia and Bosnia. The Danube or as it is called the Donau then flows into the Black Sea which used to extend almost as far as Austria and covered all the plain where to-day the Danube flows; and the sign of this is shown by the oysters and cockle-shells and scollops and bones of great fishes which are still found in many places on the high slopes of the said mountains; and this sea was created by the filling up of the spurs of the Adula range which extend to the east and unite with the spurs of the Taurus range extending to the west. And near Bithynia the waters of this Black Sea discharged themselves into the Propontis, falling into the Aegean Sea, that is the Mediterranean Sea, where at the end of their long course the spurs of the Adula range are severed from those of the Taurus range, and the Black Sea sank down and laid bare the valley of the Danube with the above-named provinces, and the whole of Asia Minor beyond the Taurus range to the north, and the plain which stretches from the Caucasus to the Black Sea to the west, and the plain of Tanais (the Don) this side of the Ural mountains that is at their feet.

So the Black Sea must have sunk about a thousand braccia to uncover such vast plains. Leic. 1 v.

In this work of yours you have first to prove how the shells at a height of a thousand braccia were not carried there by the Deluge, because they

[1] MS. has Rhine.

are seen at one and the same level, and mountains also are seen which considerably exceed this level, and to enquire whether the Deluge was caused by rain or by the sea rising in a swirling flood; and then you have to show that neither by rain which makes the rivers rise in flood nor by the swelling up of the sea could the shells being heavy things be driven by the sea up the mountains or be thrown there by the rivers contrary to the course of their waters.

Leic. 3 r.

When a river flows out from among mountains it deposits a great quantity of large stones in its gravelly bed, and these stones still retain some part of their angles and sides; and as it proceeds on its course it carries with it the lesser stones with angles more worn away, and so the large stones become smaller; and farther on it deposits first coarse and then fine gravel, and after this big and then small shingle, and after this follows sand at first coarse and then more fine; and thus continuing the water turbid with shingle and sand reaches the sea.

The shingle is deposited over the shores of the sea by the backwash of the salt waves, until at last the sand becomes so fine as to seem almost like water. Nor does this remain upon the sea shores but goes back with the wave by reason of its lightness, being formed of rotting leaves and other things of extreme lightness; and consequently being as has been said almost of the nature of water in time of calm weather it drops down and settles at the bottom of the sea, where by reason of its fineness it becomes compressed and resists the waves which pass above it on account of its smoothness; and in this shells are found and this is the white earth that is used for making jugs.

Leic. 6 v.

OF THE FLOOD AND OF MARINE SHELLS

If you should say that the shells which are visible at the present time within the borders of Italy, far away from the sea and at great heights, are due to the Flood having deposited them there, I reply that, granting this Flood to have risen seven cubits above the highest mountain, as he has written who measured it, these shells which always inhabit near the shores of the sea ought to be found lying on the mountain sides, and not at so short a distance above their bases, and all at the same level, layer upon layer.

Should you say also that the nature of these shells causes them to keep near the edge of the sea, and that as the sea rose in height the shells

left their former place and followed the rising waters up to their highest level: — to this I reply (*that in forty days the shells cannot travel*[1]) that the cockle is a creature incapable when out of water of more rapid movement than the snail, or is even somewhat slower, since it does not swim, but makes a furrow in the sand, and supporting itself by means of the sides of this furrow will travel between three and four braccia in a day; and therefore with such a rate of motion it would not have travelled from the Adriatic Sea as far as Monferrato in Lombardy, a distance of two hundred and fifty miles, in forty days, — as he has said who kept a record of this time.

And if you say that the waves carried them there, — they could not move by reason of their weight except upon their base. And if you do not grant me this, at any rate allow that they must have remained on the tops of the highest mountains, and in the lakes which are shut in among the mountains, such as the lake of Lario or Como, and Lake Maggiore[2], and that of Fiesole and of Perugia and others.

The water of the contingent seas forms the sphere of the water which has for the centre of its surface the centre of the world but not as the centre of its gravity, because in many places it is of great depth and in many of small depth, and for this reason as it is not of uniform thickness it is not of uniform weight. But merely because that thing is higher which is more remote from the centre of the world, therefore this surface not being in movement cannot remain in any place higher in one part than in another, because the highest part of the water always seeks to fill up with itself the part of it which is lower.

If the Flood passed as has been said, above the mountains of our hemisphere, without doubt it made the gravity of this our habitable part greater than that of the antipodes, and as a consequence it brought it nearer to the centre of the world than it was at first; and the part opposite was removed farther away from this centre, for which reason the aforesaid Flood submerged more than would have been submerged if such gravity had not been acquired by it on this side.

If you should say that the shells were empty and dead when carried by the waves, I reply that where the dead ones went the living were not

[1] Words crossed out in MS.

[2] MS. 'come lago di Lario, e'l Maggiore, e di Como'. Larius was however the Latin name for Lake Como.

far distant, and in these mountains are found all living ones, for they are known by the shells being in pairs, and by their being in a row without any dead, and a little higher up is the place where all the dead with their shells separated have been cast up by the waves. Near to there the rivers plunged into the sea in great depth; like the Arno which fell from the Gonfolina near to Monte Lupo and there left gravel deposits, and these are still to be seen welded together, forming of various kinds of stones from different localities and of varying colour and hardness one concrete mass. And a little farther on, where the river turns towards Castel Fiorentino the hardening of the sand has formed tufa stone; and below this it has deposited the mud in which the shells lived; and this has risen in layers according as the floods of the turbid Arno were poured into this sea, and so from time to time the bed of the sea was raised.

This has caused these shells to be produced in pairs, as is shown in the cutting of Colle Gonzoli, made sheer by the river Arno which wears away its base, for in this cutting the aforesaid layers of shells may be seen distinctly in the bluish clay, and there may be found various things from the sea.

And the earth of our hemisphere became raised up more than it was before as by degrees it became lightened of the water that flowed away from it through the straits of Gibraltar; and it was raised so much the more because the weight of the water which flowed away from it was added to that of the earth that was turned to the other hemisphere.

And if the shells had been in the turbid water of a deluge they would be found mixed up and separated one from another, amid the mud, and not in regular rows in layers as we see them in our own times.

Leic. 8 v.

As for those who say that these shells are found to exist over a wide area having been created at a distance from the sea by the nature of the locality and the disposition of the heavens, which moves and influences the place to such a creation of animal life, to these it may be answered that granted such an influence over these animals it could not happen that they were in one line except in the case of animals of the same species and age; and not the old with the young, nor one with an outer covering and another without its covering,[1] nor one broken and another whole, one filled with sea sand, and the fragments great and small of

[1] MS. e l'altro essere *colla* sua copritura.

others inside the whole shells which stand gaping open; nor the claws of crabs without the rest of their bodies; nor with the shells of other species fastened on to them like animals crawling over them and leaving the mark of their track on the oustide where it has eaten its way like a worm in wood; nor would there be found among them bones and fishes' teeth which some call arrows and others serpents' tongues; nor would so many parts of different animals be found joined together, unless they had been thrown up there upon the borders of the sea.

And the Flood would not have carried them there because things heavier than water do not float upon the surface of the water, and the aforesaid things could not be at such heights unless they had been carried there floating on the waves, and that is impossible on account of their weight.

Where the valleys have never been covered by the salt waters of the sea there the shells are never found; as is plainly visible in the great valley of the Arno above Gonfolina, a rock which was once united with Monte Albano in the form of a very high bank. This kept the river dammed up in such a way that before it could empty itself into the sea which was afterwards at the foot of this rock it formed two large lakes, the first of which is where we now see the city of Florence flourish together with Prato and Pistoia; and Monte Albano followed the rest of the bank down to where now stands Serravalle. In the upper part of the Val d'Arno as far as Arezzo a second lake was formed and this emptied its waters into the above-mentioned lake. It was shut in at about where now we see Girone, and it filled all the valley above for a distance of forty miles. This valley received upon its base all the earth carried down by the turbid waters and it is still to be seen at its maximum height at the foot of Prato Magno for there the rivers have not worn it away.

Within this soil may be seen the deep cuttings of the rivers which have passed there in their descent from the great mountain of Prato Magno; in which cuttings there are no traces visible of any shells or of marine earth.

This lake was joined to that of Perugia.

A great quantity of shells may be seen where the rivers empty themselves into the sea, because in such places the water is not very salt on account of the mixture of the fresh water which unites with it. A proof of this is to be seen where the Apennines once emptied their rivers into the waters of the Adriatic, for there among the mountains in most parts a great quantity of shells are visible together with bluish marine clay;

and all the rocks which are broken away in such places are found to be full of shells.

We know that the Arno did the same when it fell from the rock of Gonfolina into the sea which was not very far below it, because in those times it must have stood higher than the top of San Miniato al Tedesco, since in the highest summits of this [mountain] one sees the rocks full of shells and oysters within its banks; the shells did not extend in the direction of Val di Nievole because the fresh waters of the Arno did not extend so far.

How the shells were not carried from the sea by the Deluge, because the waters which came from the earth to the sea although they drew the sea towards the earth were those which smote its base, because the water which comes from the earth has a stronger current than that of the sea, and as a consequence is more powerful and enters beneath the other water of the sea, and stirs up the bottom and carries with it all the movable objects which are to be found in it such as the above-mentioned shells and other like things; and as the water which comes from the land is muddier than that of the sea it is so much the more powerful and heavier than it. I do not see therefore in what way the said shells could have come to be so far inland unless they had been born there.

If you should tell me that the river Loire which passes through France spreads itself over more than eighty miles of country when the sea is increased, because the country forms a great plain and the sea rises about twenty braccia, and that shells are sometimes found in this plain at a distance of eighty miles from the sea, the reply is that the flow and ebb in our Mediterranean seas does not cause so much variation because in the Gulf of Genoa it does not vary at all, at Venice and in Africa only a little, and where it varies only a little it covers but little of the country.

Leic. 9 r.

Refutation of such as say that the shells were carried a distance of many days' journey from the sea by reason of the Deluge.

I hold that the Deluge would not be able to carry up into the mountains objects native to the sea unless the sea had become so swollen as to form a flood so great that it even mounted above the height of these same places, and this process could not have occurred because it would have created a vacuum; and if you should say that the air would rush in there we have already concluded that what is heavy cannot be supported on what is light wherefore we conclude of necessity that this Deluge was

caused by rain water; and if this was the case all this water flowed into the sea and the sea does not flow up the mountains; and if it ran into the sea it pushed the shells along the shore into the sea and did not draw them to itself. And if you should say that because the sea was raised by rain water it carried these shells to such a height, we have already stated that things heavier than water cannot float upon its surface but remain at the bottom and are not moved from there unless by pressure from the waves. And if you were to say that it was the waves which had carried them to these high places we have proved that the waves when of great depth move in an opposite direction at their base to their movement above, this being shown by the turbidity of the sea arising from the soil that has been washed away near its shores.

An object lighter than water moves with its wave and it is left on the highest spot of the bank by the highest wave; an object heavier than water moves only when driven by its wave along the surface of its bed. And from these two conclusions which in their places will be fully proved we may conclude that the wave of the surface cannot carry shells because they are heavier than water; and consequently they will be driven by the lower wave when the wind comes from the land, because when the wind comes from the land the wave at the bottom of the sea moves in the opposite direction to the course of the wind which is then prevailing; and this moreover will not cause the shells to be carried to the mountains, because the water at the bottom which moves in the opposite direction to the wind will be so much slower than the wave of the surface as it is deeper than the height of the wave. This is evident because if the wave of the surface is the height of one braccio and there are a hundred braccia of water below it then without doubt the lower wave will be a hundred times slower than the upper wave, as is shown in the seventh proposition. The upper wave will never turn back on its base with any great force unless the depth of the water that is below the wave is equal to that of the wave.

The tiny wave which may be seen on the high seas travelling against the course of the wind will not pass over its base, that is it will not touch it but will dissolve at contact with the surface wave. I hold that such movement of water, changing from its surface to its base, resembles that which takes place on the surface between two banks, seeing that if a third of the expanse of the river be moving towards the west, another third will move towards the east and the remainder to the west; and if

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there should be another similar part there that would return to the east. The lateral movements of rivers will become slower in proportion as they are farther removed from the first current. As regards the friction created by water inside other water and moving more swiftly, whether it divides immediately, that is whether the edges of this body of water are worn away or follow one after another, that is the swifter portion carrying the less swift with it, — I maintain that this is not the case, for if it carried with it more water than usual it would grow to such a size during its long course that it would be carrying with it all the water of the river.

Why the oysters are very seldom found dead on the shores of the sea is because usually they live fastened to the rocks at the bottom of the sea and are incapable of movement except in the half which is sensitive and light. The other valve is fixed to the stone or if not fixed nature has caused them to grow larger and so to become so heavy that the small amount of undulation which takes place in the vast depths of the sea cannot easily dislodge them. But the valve that has the power of movement is very light and performs the same function for it as the lid does for a chest. And when the oyster feeds, its food walks into the house of its own accord, for it consists of certain animalculae which feed round the shells of the dead ones and which consequently are found where there are a great many shells of dead oysters. If the Deluge had carried the shells for distances of three and four hundred miles from the sea it would have brought them with the various different species mixed up, all heaped up together; but even at such distances from the sea we see the oysters all together and also the shell-fish and the cuttle-fish and all the other shells which stand together in companies, found all together dead, and the single shells are found one at a distance from another as we see them every day on the sea shores.

And we find the oysters together in very large families, among which some may be seen with their shells still joined together, which serves to indicate that they were left there by the sea and that they were still living when the straits of Gibraltar were cut through.

In the mountains of Parma and Piacenza multitudes of shells and corals filled with worm-holes may be seen still adhering to the rocks, and when I was making the great horse at Milan a large sack of those which had been found in these parts was brought to my workshop by some peasants, and among them were many which were still in their original condition.

Under the ground and down in the deep excavations of the stone-quarries timbers of worked beams are found which have already become black. They have been found during my time in the excavations made at Castel Fiorentino, and they were buried there before the sand deposited by the Arno in the sea which then flowed over the spot had been raised to such a height, and before the plains of the Casentino had been so much lowered by the removal of the earth which the Arno was continually washing away from them.

In Candia, in Lombardy, near to Alessandria della Paglia, while some men were engaged in digging a well for Messer Gualtieri who has a house there, the skeleton of a very large ship was found at a depth of about ten braccia beneath the ground; and as the timber was black and in excellent condition, Messer Gualtieri thought fit to have the mouth of the well enlarged in such a way that the ends of the ship should be uncovered.

The red stone of the mountains of Verona is found with shells all intermingled which have become part of this stone, and their mouths have become sealed up by the cement of which the stone has been formed, and portions of them have remained separated from the rest of the mass of stone which enclosed them, because the outer covering of the shell intervened and thus prevented them from uniting; and in other cases this cement has petrified the old broken outer covering.

And if you should say that these shells have been and still constantly are being created in such places as these by the nature of the locality and through the potency of the heavens in those spots, such an opinion cannot exist in brains possessed of any extensive powers of reasoning because the years of their growth are numbered upon the outer coverings of their shells; and both small and large ones may be seen, and these would not have grown without feeding or feed without movement, and here they would not be able to move. Leic. 9 v.

How the northern bases of certain Alps are not yet petrified; this is seen clearly where the rivers which cut through them flow towards the north, for these cut through the strata of the living rock in the mountain heights; and where they unite with the plains these strata are all of clay that serves to make pots, as is seen in the Val di Lamona where the river Lamona as it issues from the Apennines does these same things in its banks.

How the rivers have all sawn through and divided the members of the great Alps one from another; and this is revealed by the arrangement of the stratified rocks, in which from the summit of the mountain down to the river one sees the strata on the one side of the river corresponding with those on the other. How the stratified rocks of the mountains are all in layers of mud deposited one above another by the floods of the rivers. How the different thicknesses of the strata of the rocks are created by the different floods of the rivers, that is the greater and the less floods.

How between the various layers of the stone are still to be found the tracks of the worms which crawled about upon them when it was not yet dry. How all the marine clays still contain shells, and the shell is petrified together with the clay. Of the stupidity and ignorance of those who imagine that these creatures were carried to such places distant from the sea by the Deluge.

How another set of ignoramuses maintain that nature or the heavens have created them in these places through celestial influences; as though in those places one did not find the bones of fishes which have taken a long time to grow; as though one could not count on the shells of cockles and snails the number of the months and years of their lives, just as one can on the horns of bulls and wethers and in the ramification of plants when they have never been cut in any part. And having shown by these signs that the length of their life is evident, it must needs be admitted that these animals could not live without the power of movement in order to seek their food, and we cannot see that they are equipped with any instrument for penetrating the earth or stone in which they find themselves enclosed. But how could one find in the shell of a large snail fragments and bits of many other sorts of shells of different kinds unless they had been thrown into it by the waves of the sea as it lay dead upon the shore like the other light things which the sea casts up on the land?

Why do we find so many fragments and whole shells between the different layers of the stone unless they had been upon the shore and had been covered over by earth newly thrown up by the sea which then became petrified? And if the above-mentioned Deluge had carried them to these places from the sea, you would find the shells at the edge of one layer of rock only, not at the edge of many where may be counted the winters of the years during which the sea multiplied the layers of sand and mud brought down by the neighbouring rivers, and spread them

over its shores. And if you should wish to say that there must have been many deluges in order to produce these layers and the shells among them it would then become necessary for you to affirm that such a deluge took place every year. Further as regards the fragments of these shells, it must be presumed that in such a locality there was a sea beach, where the shells were all cast up broken and divided and never in pairs as they are found in the sea when alive, with two valves which form a covering the one to the other. And within the layers of the banks of rivers and of sea shores they are found broken; and on the edges of the rocks they are found infrequently and with the two valves together, like those which were left by the sea buried alive within the mud which afterwards dried up and in time became petrified.

Leic. 10 r.

And if you should say that it was the Deluge that carried these shells away from the sea for hundreds of miles, this cannot have happened for the Deluge came about as the result of rains, because the rains naturally cause the rivers together with the objects carried by them to rush towards the sea and they do not draw up to the mountains the dead things on the sea shores.

And if you should say that the Deluge then rose with its waters above the mountains, the movement of the sea in its journey against the course of the rivers would have been so slow that it would not have been able to carry things heavier than itself floating in it; or if somehow it had had them floating in it then as it subsided it would have left them strewn about in various places. But how are we to account for the fact of the corals being found every day round about Monferrato in Lombardy with worm-holes in them, sticking to the rocks which have been left bare by the currents of the rivers? And the said rocks are all covered with stocks and families of oysters, which as we know do not move but always remain fixed by one of their valves to the rock, having the other open in order to feed upon the animalculae that are swimming about the waters and which while hoping to find good pasture become the food of the above-mentioned shells. Is it not found that the sand that is mixed with the seaweed has become petrified when the seaweed which has divided it has become less? And of this the Po affords instances every day in the debris of its banks.

At Alessandria della Paglia in Lombardy there is no other stone from which to make lime except such as is made up of an infinite number of

things native to the sea; but it is now more than two hundred miles distant from the sea.

In eighty-nine [the year 1489] there was an earthquake in the sea of Satalia near to Rhodes, and it opened the depths of the sea and into the opening that was made such a torrent of water was poured that for more than three hours the bed of the sea lay bare because of the water which had been lost from it, and then it closed up again to its former level. Whatever changes may occur in the weight of the earth the surface of the sphere of waters will never cease to be equidistant from the centre of the world.

The bosom of the Mediterranean like a sea received the principal waters of Africa, Asia and Europe; for they were turned towards it and came with their waters to the base of the mountains which surrounded it and formed its banks.

And the peaks of the Apennines stood up in this sea in the form of islands surrounded by salt water. Nor did Africa as yet behind its Atlas mountains reveal the earth of its great plains naked to the sky some three thousand miles in extent; and on the shore of this sea stood Memphis; and above the plains of Italy where flocks of birds are flying to-day fishes were once moving in large shoals.

Leic. 10 v.

That there are springs which as a result of earthquakes or other unforeseen causes suddenly burst forth and as suddenly fail. And this happened in a mountain in Savoy where certain woods sank in and left a very deep abyss; and at about four miles distance from there the ground opened on the slope of a mountain and threw out suddenly an immense flood of water, which swept through a whole valley of tilled fields vineyards and houses and did irreparable damage wherever it spread.

That there are many springs which come to fail suddenly: and this happens through some subsidence in a cavern that is pent up within the body of the earth whereby the passage of the said springs is blocked and hindered.

That there are many springs which spring up suddenly and are permanent; and this occurs when some river in its long course has worn away so much of the mountain that it bursts open springs of water which have a passage there; it may also occur as I said before when a cave has fallen in ruin and blocked up a spring, so that its water has been forced

up to such a height in this cavern that it reaches the level of some fissure in the rock and so has made its escape, creating a new river.

That many springs of salt water are found at great distances from the sea; and this may have come about because these springs have passed through some mine of salt like that in Hungary where the salt is hewn out of immense quarries just as blocks of stone are.

That within rocks surrounded by salt waters and within these salt waters themselves in the same way there rise in many places springs of fresh water.

That there are in many places springs of water which rise for six hours and sink for six hours; and I have myself seen one above Lake Como called Fonte Pliniana which increases and decreases in this way to such an extent that when it is flowing it grinds two mills, and when it fails it falls so low that it is as though one were looking at the water in a deep well.

Leic. 11 v.

A tempest on the sea is much more violent near to the shore than on the high sea; and this is the case because the recoil of the waves is striking the sea on the one side and the wind strikes it on the other, and this causes the wave to be higher and more topped with spray.

Leic. 12 r.

How the flow and ebb of the tide is not uniform, for on the coast of Genoa there is none; at Venice it makes a variation of two braccia; between England and France of eighteen braccia. How the current that flows through the straits of Sicily is very powerful because through these there pass all the waters of the rivers which discharge themselves into the Adriatic.

When the surface of the water consists of small shaded waves which form themselves into lines that meet in an angle,[1] the fact shows that the bed of the river is not far away, and it is also produced by the sand thrown off by the water as it passes through a confined space such as the arch of a bridge or the like. When the lines of its surface form a curved or crescent shaped figure this is a sign of its lack of depth, for it is caused by the sand carried by the greater current into the lesser, that is by the less sluggish to the more sluggish, since both of them have but little

[1] These words serve exactly to describe the treatment of the waves in Botticelli's 'Birth of Venus'.

speed or depth. When the surface of the water shows itself as a straight line or just a little bent with tiny waves and these with but little sheen or brightness there is very little depth there; and this is caused by two currents one slower than the other which join together again below the island that divides them higher up; for these have caused the sand which each bore with it to settle, because it is deposited at the point of their junction, since at this spot their movement ended.

Leic. 13 r.

Why the bones of great fishes and oysters and corals and various other shells and sea-snail are found on the high tops of mountains that border on the sea, in the same way in which they are found in the depths of the sea?

How the rocks and promontories of the seas are being continually destroyed and worn away.

How the Mediterranean seas will lay bare their depths to the air, and will only keep the channel of the greatest river that flows there which will run to the ocean and there discharge its waters together with those of all the rivers which are its tributaries.

How the brightness of the atmosphere is caused by the water that is dissolved in it and that has formed itself into imperceptible particles which after taking the light of the sun from the opposite side give back the brightness that is visible in this atmosphere; and the blue that appears in it is caused by the darkness which is hidden behind this atmosphere.

Why the Adige rises every seven years and falls every seven years, and is the cause of famine or abundance?

Why following on great pestilences the rivers become deeper and run clear though previously they were wide and of but little depth and always turbid?

Leic. 20 r.

The sea shuts itself in among the great valleys of the earth; and this earth serves as a cup for the sea; and the lips of the cup are the shores of the seas, and if these were taken away the sea would cover all the earth; but because every part of the earth that is uncovered is higher than the greatest height of the sea this sea cannot flow over it, but merely contents itself with covering that earth which serves as its bed. Many,

however, in ignorance of this thing, have presumptuously written how the surface of the water of the sea is higher than the highest mountain that can be found; as regards which thing, although they see the bank higher than the water, they are extremely blind who say that it is a miracle for the water in the midst of the sea to be higher than its shore or than the promontories which jut out over the sea. But this fallacy arises from the fact that they imagine a straight line of indefinite length extended above the middle of the sea, which without doubt will be higher than the said shores, because the earth is a sphere and its surface forms a curve, and the farther it is removed from its middle the more it becomes remote from the said straight line; the fact of it becoming lower in this condition is that which has deceived them; and it is this reason which will be brought forward by the adversary. 'That part of the water will be higher which is more remote from the centre of the world'.

Observe that here there is no place for the straight unending *a b* of the adversary, because *b g* exceeds the line *e g* by the whole part *b n*; and by this it is confirmed that the surface of the seas which are joined together are equally distant from the centre of the earth. 'The highest mountains are as far above the sea as the lowest depths of the sea are below the air.'

For a long time the water of the Mediterranean flowed through the Red Sea which is a hundred miles wide and fifteen hundred miles long, all full of reefs; and it has worn away the sides of Mount Sinai, which circumstance does not point to a flood from the Indian Ocean having struck upon these shores but to a great deluge of water which carried with it all the rivers which are very numerous round the Mediterranean, and also the ebb of the sea. And afterwards Mount Calpe was cut through in the west, three thousand miles distant from this spot, and separated from Mount Abyla; and this cutting took place at the lowest spot in the wide plains which lie between Abyla and the ocean, in the low part at the foot of the mountain, helped by the hollowing out of some valley caused by some river which must have flowed there. Hercules came to open the sea in the west, and then the waters of the sea commenced to flow into the western ocean; and as a consequence of this great fall the Red Sea remained the higher, and therefore the waters have ceased to flow in that direction but have always ever since poured through the Straits of Spain [Gibraltar].

On the shores of the Mediterranean three hundred rivers are found

discharging their waters and there are some forty thousand two hundred harbours, and this sea is three thousand miles in length. Many times the swollen waters of the sea have been heaped up by its reflux, by the western gales, the flooding of the Nile and of the rivers which flow into the Black Sea. So the seas came to be so much raised that they have flowed over many countries causing immense floods; and these floods occur at the time when the sun melts the snow on the high mountains of Ethiopia which rise into the cold regions of the air; even so is it as the sun approaches near to the mountains of Sarmatia in Asia and to those in Europe; so that the accumulations occasioned by these three above-mentioned things are and have been the cause of the greatest floods, namely the ebb of the sea, the western wind and the melting of the snows. And all things have been overwhelmed in swirling flood in Syria, Samaria, Judaea between Sinai and Lebanon, and in the rest of Syria between Lebanon and Mount Taurus, and in Cilicia within the mountains of Armenia, and in Pamphylia and in Lycia within the Celenian mountains, and in Egypt as far as Mount Atlas. The Persian Gulf which was once a vast lake of the Tigris and had its outlet into the Indian Ocean, has now worn away the mountain which served it as a bank, and become the same level as the Indian Ocean. And if the Mediterranean had continued to find an outlet through the Gulf of Arabia it would have produced the same result, that is it would have caused its level to become the same as that of the Indian Ocean.

[*With drawing*]

In this one has to imagine the earth sawn through the centre; and it will show the depth of the sea and of the earth; [and how] the springs start from the bottoms of the seas, and wind their way through the earth, and raise themselves to the summits of the mountains, and flow back again through the rivers, and return to the sea.

Since things are far more ancient than letters, it is not to be wondered at if in our days there exists no record of how the aforesaid seas extended over so many countries; and if moreover such record ever existed, the wars, the conflagrations, the changes in speech and habits, the deluges of the waters, have destroyed every vestige of the past. But sufficient for us is the testimony of things produced in the salt waters and now found again in the high mountains, sometimes at a distance from the seas.

Leic. 31 r.

That part of the flow and ebb of the sea will be of greater variety from its greatest height to its lowest depth which is nearest to its cause.

There is great variation between the ebb and flow of the sea in the vicinity of those places at which the springs of the waters depart from the depths of the seas in order to supply a perpetual stream of water to the rivers which afterwards descend from the high mountains.

These springs are of two natures, of which one is of those that are continually discharging themselves in the rivers; and there are others that pour themselves into the sea, and rise fresh above the other salt waters: which thing proceeds from the fact of them being born from the lakes that lie open to the air, which are higher than the waters of the sea, otherwise this rising would not take place. And yet one might say that just as the springs of the mountains are poured to their feet, so such springs might also be poured beneath the sea.

There is a spring in Sicily which as it rises at certain seasons of the year throws out chestnut leaves in large quantities. Since however chestnut trees do not grow in Sicily this spring must have come originally from some underground lake in Italy and then passed beneath the sea and afterwards found outlet in Sicily.[1]

In the Bosphorus the Black Sea always flows into the Aegean, never the Aegean into it. This is due to the fact that the Caspian Sea, five hundred miles to the east, together with the rivers that flow into it, is always discharging itself through subterranean channels into the Black Sea; and the Don and also the Danube do the same; so that as a consequence the waters of the Black Sea are always higher than those of the Aegean, and it follows that the higher always descend into the lower and never the lower into the higher.

Some say that the waters which rise in the summits of the high mountains, are part of the water of the sea which is higher than the summits of the highest mountains that exist; which serves them to prove that the surface of the sea is lower than any part of the earth that stands above the waters, or than any part of the surface of a river which flows into this sea.

Others say that the waters which flow above the high summits of the mountains are descended from the higher mountains of the world which

[1] Richter points out that the chestnut is a common tree in Sicily and suggests that Leonardo may have written 'Cicilia' in mistake for Cilicia.

are covered with snow that melts during the summer. But this opinion is shown to be incorrect, for if it were the case that the melting snows of summer entering into subterranean caverns and through the springs in the ground had sent the water in the tops of the mountains lower than the mouths of the springs, there would be more water in these springs in summer than in winter, but experience shows that the opposite is the case.

All the outlets of the waters which proceed from the mountain to the sea carry stones from the mountains with them to the sea; and by the backwash of the ocean surges against their mountains these stones were thrown back towards the mountain; and as the waters moved towards the sea and returned from it the stones turned with them, and as they were rolled back their corners struck together, and such parts of them as offered least resistance to the blow were worn away and make stones without angles of a round shape, such as are to be seen on the shores of Elba. And those remain bigger which are carried the least distance from their native spot, and in like manner the stone becomes smaller which is transported farther away from the aforesaid spot, for in the course of its progress it becomes changed to fine shingle and then to sand and finally to mud. After the sea had receded from the aforesaid mountains the salt deposit which it left behind with the other moisture from the earth formed a compound with the shingle and sand so that the shingle became changed to rock and the sand to tufa.

And of this we may see an example in the Adda where it emerges from the mountains of Como, and in the Ticino the Adige the Oglio and the Adriano from the Austrian Alps; and in the same way with the Arno from Monte Albano round about Monte Lupo and Capraia, where the largest rocks are all formed of solidified shingle of different varieties of stone and of different colours.

That thing which is lighter will be carried farther by the rivers from the place whence its waters snatched it away; and so that which is heavier will be removed a less distance from the place at which it was separated. That percussion of the water carries away more of the bank of rivers which strikes this bank at more equal angles; and so conversely it will carry away less when the angles are more unequal. Leic. 31 v.

There are as many differences in the resistance made by water

beneath that which is supported by it as there are differences in its heat or cold.

Given two rivers of equal volume of water at their entrances, their exits will be equal; that is, given an equal volume of water in an equal time, even though the rivers may vary in length, breadth, slant and depth and the one be twisted and the other straight; or though both be twisted but the shapes of their curves are unlike; or one be of uniform breadth and the other of varying breadth; and if both vary their variation may be different; one may be of uniform depth and the other of varying depth; and should both depths vary in themselves their variation may not have any kind of likeness; and the whole of one may be uniformly swift and the other uniformly slow, or the slowness and swiftness of one may be mixed, that is where it runs and where it lingers, where the waters fall perpendicularly and where they rise in a swirling flood; and the fact that there exist in these two rivers infinite varieties of currents in breadth, length, slant and depth will not therefore prevent the equal entrance of the one from being equal to its exit, and the equal entrances of the one and the other from being equal in their exits.

If the Mediterranean Sea departs from its site it raises the sphere of the water and occupies new valleys, and consequently the centre of gravity of this increase will be round the antipodes; and so on that side the weight grows, and on this there is lacking the whole amount of the weight of the water that has departed from there; and although this position may be filled up by that earth which was carried by the rivers into this Mediterranean, the centre of its gravity will be opposite to that of the sphere which has been increased in the antipodes; and so on this side the weight is not increased by the earth which has been removed as a substitute for the sea which has been expelled, because this earth remains in our hemisphere, that is, the centre of its gravity, but it is nevertheless true that the whole weight of the water is here diminished. Therefore the centre of the world will become nearer to our antipodes, lightening itself here of the weight of the water which has departed; and the summits of the mountains will raise themselves more from this centre: until such a point that the rivers which accompany the Nile after much rambling about through the great plain into which the Mediterranean is divided will carry through the straits of Gibraltar all the part of the soil that makes it turbid; and in course of time they will place as much soil in the ocean beyond the straits of Gibraltar as is found between

Libya and the sea, and between the Alps and the said sea; and so again the centre of the world will become nearer the centre of the weight increased to the ocean, and the parts lightened will become more remote from this centre. So then it is concluded that the more the soil is removed from us the more it lightens our regions; as a consequence the more it is removed from the centre of the earth the more the waters consume it and the more again it becomes light; and so it will continue until all the earth laid bare is carried to the sea by the Nile or by the rivers that are poured into it.

And so the earth that is found in the rivers that now pour themselves into the Mediterranean will be carried by the Nile together with the turbid water that remains in it to the ocean.

So then the sea will return to cover the places where were formerly the roots and bases of the mountains, and it will cover the earth.

It is not denied that the Nile is always turbid as it enters the Egyptian sea, and that this turbid condition is due to the soil which this river carries away continually from the places through which it passes, and this soil never returns back nor does the sea receive it except just to cast it back upon its shores; behold the ocean of sand beyond Mount Atlas where it was once covered with salt water.

The water that is found in the highest mountains is not there because it has been drawn there by the heat of the sun for but little of this heat passes downwards, as is seen below La Vernia, where the power of the sun is not sufficient to melt the ice during the greatest heat of summer, but it remains there in the hollows in which it has been lying since the winter. And on the northern slopes of the Alps, where the sun does not strike, the ice never melts, because the heat of the sun cannot penetrate the small thickness of the mountains; still less therefore will the vast space that lies between the summits of the great mountains and the depths of the watery sphere be penetrated by this heat of the sun which would have to pass beneath the base of this mountain. If you should say that the earth's action is like that of a sponge which when part of it is placed in water sucks up the water so that it passes up to the top of the sponge, the answer is that even if the water itself rises to the top of the sponge, it cannot then pour away any part of itself down from this top, unless it is squeezed by something else, whereas with the summits of the

mountains one sees it is just the opposite, for there the water always flows away of its own accord without being squeezed by anything.

Perhaps you will say that water can only rise the same distance as it descends; and that the surface of the sea is higher than the summits of the highest mountains. The answer to this is that the exact opposite is the case, for the lowest part visible to the sky is the surface of the sea, since water does not move of itself unless to descend, and so descends when it moves; as therefore the rivers which stretch from the summits of the mountains to the sea are everywhere in movement they are therefore everywhere descending, and when they come to the sea they stop and end their movement; for which reason one must conclude that they are stationary in the lowest reaches of the river. But if you should say that the farther the sea is away from the shore the more it rises up and so it comes to equal the height of the high mountains; it is shown here that a thing is higher which is farther removed from the centre of the earth, and if the element of water is spherical the definition of spherical bodies is those in which every part of the surface is equidistant from the centre. So therefore the shore of the sea is as high as its centre, and whatever may be discerned from the shore is higher than any part of the sea; and the distance that there is from the summits of the high mountains to the centre of the earth is greater than the distance from this centre to the sea shore: this then is our conclusion.

And if you should say as has been said that the sun sucks up and draws the waters from the roots of the mountains to their summits, then as the heat draws the moisture to itself the heat which is more powerful would draw to itself a greater amount of water than the less powerful. In summer therefore during the fiery heats the springs of the waters would have to rise higher into the summits of the mountains than they do in winter; but we see it is the contrary seeing that in summer the rivers lack a great part of their waters.

Leic. 32 v.

OF THE ORIGIN OF RIVERS

The body of the earth like the bodies of animals is interwoven with a network of veins which are all joined together, and are formed for the nutrition and vivifying of this earth and of its creatures; and they originate in the depths of the sea, and there after many revolutions they have to return through the rivers formed by the high burstings of these veins.

And if you should wish to say that rains in winter or the melting of the snow in summer were the cause of the origin of the rivers, one may offer as an instance the rivers which originate in the torrid regions of Africa in which it does not rain still less does it snow, because the excessive heat always dissolves into air all the clouds which are driven there by the winds. And if you should say that these rivers which become big in July and August are from the snow which melts in May and June as the sun approaches nearer to the snowfields of the mountains of Scythia, and that the snow thus melted collects in certain valleys and forms lakes, into which it enters by springs and underground caverns, afterwards emerging to form the source of the Nile, this is incorrect because Scythia lies below the source of the Nile, and Scythia moreover is only four hundred miles from the Black Sea whereas the source of the Nile is a distance of three thousand miles from the Egyptian sea into which it pours its water.

Leic. 33 v.

In the western parts near to Flanders the sea rises and falls about twenty braccia every six hours; and twenty-two when the moon is favourable; but twenty braccia is its usual variation and this as is clearly seen is not caused by the moon. This variation in the rising and falling of the sea every six hours may occur through the swelling up of the waters which are poured into the Mediterranean by the number of the rivers from Africa Asia and Europe that pour their waters into this sea; and this gives back to the ocean through the straits of Gibraltar between the promontories Abyla and Calpe the waters given to it by these rivers.

This ocean as it extends between the island of England and other islands farther north, comes to swell up and form a bore at the mouths of certain gulfs, which, being as it were seas, with the surface separated from that of the central body of the earth, have acquired weight, and this, as it exceeds the force of the incoming waters that occasioned it, causes this water to take again an impetus contrary to that of its approach, and so creates an impetus contrary to that which the waters have given the straits, and especially against the straits of Gibraltar, which for as long as this is going on remain in swirling flood, holding back all the water recently given them at that time by the aforesaid rivers; and this would seem to be one of the reasons which may be assigned for this ebb and flow; as is proved in the twenty-first of the fourth of my book on Theory. This would occur when the water that formed the springs of rivers was caused by rain or melting snow. But if

these springs had their origin in the depths of the sea this reason would not exist, for at their beginning the sea would give them as much water as the rivers gave the sea, namely what they received from the ends of their springs; and so for this cause the sea would not increase or grow less.

The stratified rocks are created in the vast depths of the seas because the mud which the storms detach from the sea coasts is carried out to the deep sea by the recoil of the waves; and after these storms it is deposited upon the bottom of the sea, and as no storm can penetrate the sea on account of the great distance that it is below the surface it lies there motionless and becomes petrified; and sometimes it remains in the form of white clay which serves for making pots; and thus with blocks set at different angles it is made up of layers of as many different thicknesses as are the differences in the storms whether greater or less. Leic. 35 r.

WHETHER THE EARTH IS LESS THAN THE WATER

Some assert as a fact that the earth which is not covered by the waters is much less than that which is covered by them; but since the size of the diameter of the earth is seven thousand miles, it may be concluded that as the water is almost universally of but little depth its weight bears no comparison to that of the earth. The answer to these is that the water which is poured into the atmosphere which becomes united as it rises to the cold region of the atmosphere is very heavy in weight and falls in great deluges and floods. And how do we know whether the earth has enormous caverns with reservoirs of water?

And the innumerable springs which are fed by as many streams of water, as are seen in the formation of the rivers? Take as an instance the Caspian Sea which is very great.

Always the centre of the sphere of the water, but not of its weight, because it is not of equal thickness spread over the earth, will be concentric with the centre of the world; and it is the same as regards the centre of the gravity of the earth and of the waters joined together, but not of its gravity nor of its magnitude; and if the earth of itself were spherical and without water within itself, then the water would clothe it with uniform size and weight; and so the centre of the world would remain centre of the sphere and magnitude of the water and of its weight; and so it would remain centre of the sphere and magnitude of the

earth, and centre of its gravity; consequently as the earth is mixed and full of the ramifications of the waters within itself, is in some parts spread out in some compact, in some soil, in some rock, this earth has not in itself a centre of sphericity or a centre of gravity, and this especially through it having water and earth above the sphere of the water, which give weight to it as though it was the weight of the earth.

Consequently by this one concludes that the gravity of the earth and the water joined and mingled together have usually their centre concentric with the centre of the world, which centre is also the centre of the spherical surface of the water, and not of its weight, as I have said above; and this surface of the sphere of the water is broken and divided by the earth which borders on the air.

If the earth were entirely submerged by the water, even though it was of varied and irregular shape it would have the centre of its natural gravity concentric with the centre of the world and of the surface of the sphere of water, but not with the centre of its natural or even of its accidental gravity.

That earth which is not covered by the waters will be much heavier than that which is beneath this water.

The centres of the heavy bodies are three and they are differently situated, seeing that sometimes they are joined together; and here accidental gravity dies; sometimes there are two together and the third is separated from them; and here accidental gravity arises; and sometimes they are placed together in three different positions, the one from the other: and the first is the centre of the magnitude, the second is the centre of its natural gravity, and the third the centre of the accidental gravity.

The centre of the magnitude is that which is separated equally from the opposite extremities of the body that encloses it whether it be uniform or not; and it is sufficient that it is situated at an equal distance from the opposite extremities of a staff, as of a cloth of any material. And these are joined together in a body of perfect sphericity and uniform substance and density, because here there are only two and they are concentric.

Necessity makes the machine of the earth empty of earth and full of water, after the fashion of a vessel filled with water:

This is confirmed by the tenfold proportion which the four elements have between them, which is seen of the air with the earth of which the proportion is a hundredfold, because the thickness of the air has been

measured between the comet which is in the uppermost part of the air and with the surface of the sphere of the water which is in the lowest part of the sphere of the air. Now the water may be said to have as much earth uncovered which projects above the surface of the sphere of the water, as that which is lacking from the surface of the water towards the centre of the world, that is, I consider that the highest mountain that there is in the earth is as far above the surface of the sphere of the water as the greatest depth of the sea is below this surface of the sea. It follows that if one were to fill up the part wanting in the sea with the excess of the earth, that this earth would remain spherical and entirely covered by the sphere of the water. But, so far as one can discern, this sphere of water, or you may say element, would not be ten times as great as the sphere of the earth, but far from being ten times it would not attain to the relation of equality, because one sees clearly that the sphere of the water would not rise a mile above the sphere of the water, that is it would not raise itself to the altitude of the highest mountain; which thing however would take place when all the earth uncovered was everywhere as high as this highest mountain.

Therefore it is concluded that the remainder of this water stays in the body and springs of the earth, in which it may have fallen over a wide area, and lightened the spot from whence it separated itself, as is represented opposite in B.

In two ways the gravity of the earth can have its centre concentric with the centre of the world, that is if it is either altogether submerged by the waters or has its opposite side out of the waters of equal weight.

The centre of the gravity of the water and of the earth might be concentric with the centre of the world if the earth were perfectly spherical. The centre of the world would then be the centre of the sphere of the earth, as of the sphere of the water. But it would not produce land animals.

Leic. 35 v.

OF THE EARTH IN ITSELF

The fact of the summits of the mountains projecting so far above the watery sphere may be due to the fact that a very large space of the earth which was filled with water, that is the immense cavern, must have fallen in a considerable distance from its vault towards the centre of the world, finding itself pierced by the course of the springs, which continually wear away the spot through which they pass, having in

them some of the air above; because water has no weight unless it sends a wave out of its level through the air, and it is this wave alone that has weight and falls and wears away the base. Now this great mass has the power of falling, being the centre of the world within the water: it balances itself with equal opposing weights round the centre of the world, and lightens the earth from which it is divided; and it removed itself immediately from the centre of the world and rose to the height, for so one sees the layers of the rocks, formed by the changes which the water has undergone, at the summits of the high mountains.

Subsidence of lands, as in the Dead Sea in Syria, to wit Sodom and Gomorrah.

It must needs be that the water is more than the land; and the part uncovered by the sea does not reveal it; it must needs be therefore that there is a great mass of water within the earth, in addition to that which is diffused through the lower parts of the atmosphere and runs through the rivers and springs.

I say that it is not necessary that the centre of the world be situated more in the earth than in the water, because the gravity of the earth and of the water, joined together in any manner whatever, rests with weights of gravity situated oppositely around the centre of the world; and the earth does not expect to have parts of itself equally distant from this centre, but weights equally heavy placed opposite; and in this case the water being mingled with various ramifications of springs together with the earth, cannot give of itself weights equally distant from this centre, but will have a surface equidistant from this centre.

Now if it is as has been said, it is possible, the centre of the world being situated in the water, that on some occasion, through the constant friction that the water has through the springs through which it passes, it may have so widened these springs that the part of the earth which is interposed between these springs, exhausting the tenacity of the remainder, [brings it about] that the gravity, which it has acquired through being above the water, has detached itself from this remainder and has fallen towards the centre and made this concentric with the centre of its gravity. And through this the remainder of the earth having made itself lighter by that part from whence the said gravity fell, will of necessity remove itself from the centre of the world, and the earth and the mountains will emerge out of the sphere of the water

lightened by this part, and will also make itself lighter by the weight of the water which rested upon it, and will come so much the more to raise itself towards the sky. And the sphere of the water in this case does not change its position, because its water fills up the place from which the gravity of that part of the earth that fell divided itself; and thus the sea remains in itself without change of height. And this may also be the reason why the marine shells and oysters that are seen in the high mountains, which have formerly been beneath the salt waters, are now found at so great a height, together with the stratified rocks, once formed of layers of mud carried by the rivers in the lakes swamps and seas; and in this process there is nothing that is contrary to reason.

Given a perfectly smooth surface the water will not rest upon it: given a spherical surface the water will instantly rest there: which sphericity will be the sphere of the water.

The strata or layers of stone do not continue to any great distance underneath the roots of the mountains because they are made of earth that is used for making vessels and is full of shells; and also these go only a short distance below because one finds the ordinary earth there, as is seen in the rivers which flow through the Marches and the Romagna, after they have issued from the Apennines.

You have now to prove how the shells are not produced except in salt waters, and that this is the case with almost all kinds; and how the shells of Lombardy are found at four levels. And so it is with all which are made at different periods of time; and these are found in all the valleys that open out into the seas.

Leic. 36 r.

XV

Topographical Notes

'How in all travels one may learn
This benign nature so provides that all over the world you find something to imitate.'

[*With drawings*]

Four braccia in length, two and a half braccia in width two and a quarter braccia in thickness.

And thus are the stones which stand in the front of the mole which is at the harbour of Civita Vecchia.

Projection.

Half a braccio. Front of the wall of the harbour of Civita.

C.A. 63 V. b

IN SARDINIA AT ANTENORO

[*Drawing a b*]

Here the two streams of the waters clash together in the line *a b*, and in such percussion they make a complete circle, one with another, striking from the surface to the base.

And this revolving mass after being formed is driven away from the position where it was created by the rush of the waters coming above it; and in such a change this revolving mass has acquired two movements, that is the natural movement round its centre and secondly that which it acquires from one place to another. This therefore will be a direct revolving movement, which when it occurs in the water or amid the air dislodges the soil with much hollowing of it out and scraping of it away.

Where the streams of the waters are equal[1] the revolutions made by the waters as they meet will follow a straight line; but if the streams of the waters are unequal the shock of the waters clashing together will impel the revolving movements towards the bank of the less powerful stream, which as it burrows down with its two sets of movements, namely the straight and the revolving, goes hollowing out the base of the banks, and the upper parts which were upheld by these falling headlong as their foundations crumble, are worn away anew by this eddying movement.

When the streams of the waters are unequal these waters as they meet go ranging round, the less powerful stream entering with the branches of its lower eddies underneath those of the upper eddies which are made by the more powerful stream.

When the water of greater power strikes the water of less power the

[1] MS. has 'non sono equali'.

line of eddies describes a curve, entering in convex form into the body of the water of greater power.

When the curving line of the eddies enters in its convexity within the water of less power this water remains within its limits without moving; at this stage it swells up and raises itself and acquires gravity, and so from the weight that it has acquired it multiplies in power and makes headway against the water which at first overcame it, so that the line of eddies is curved in a contrary direction and becomes concave where it was formerly convex, and thus the lesser water is often driven by the greater and the greater by the lesser, but the lesser is driven farther in proportion as it is of less power.[1]

C.A. 77 r. b

Mortar-pieces for the [fleet?] at Venice, in the way that I said at Gradisca, in Friuli, and in the V[eneto].

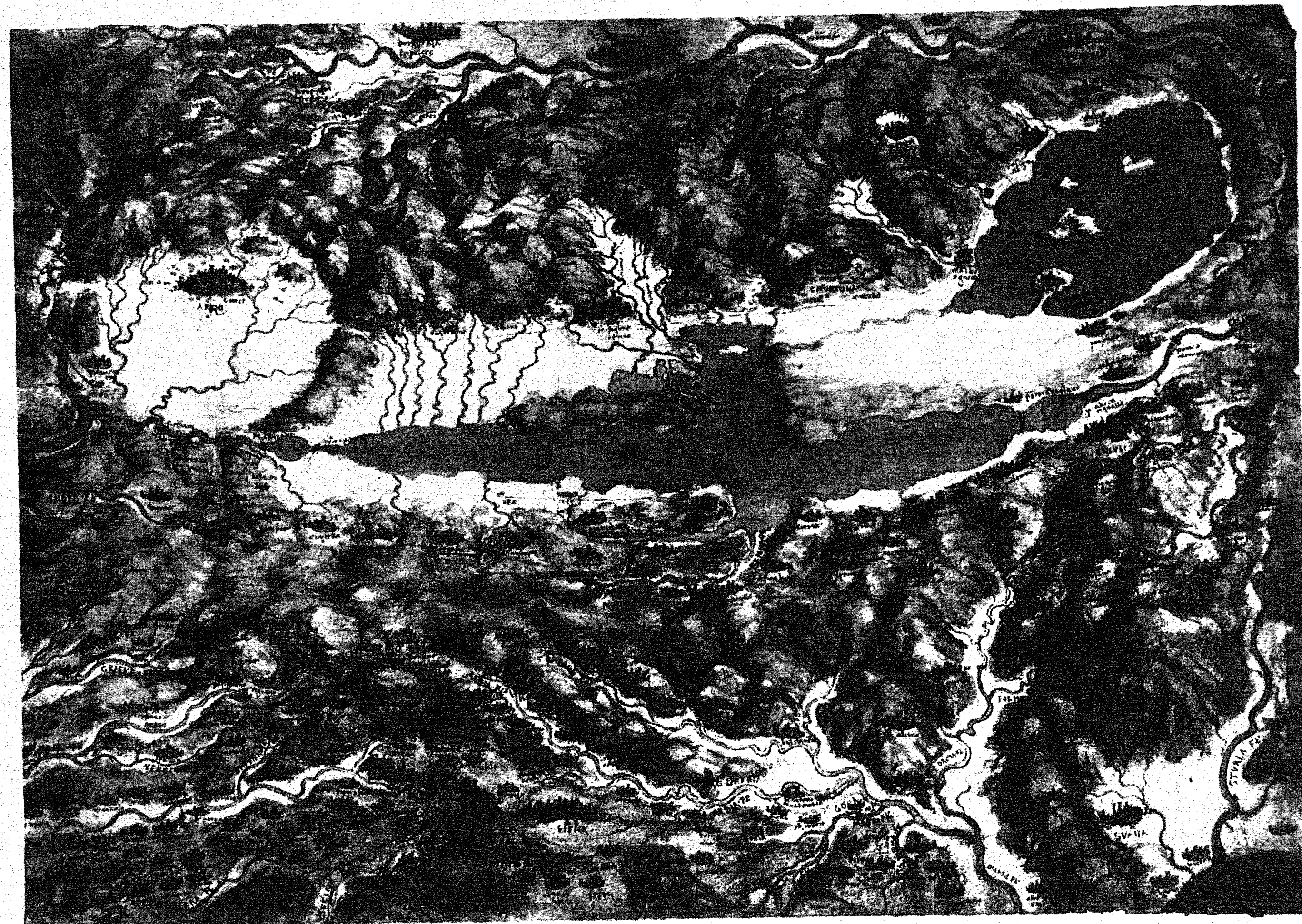
(Bombarde [. . .] llio [naviglio?] a Vinegia, col modo che io detti a Gradisca [. . .] friglioli [?] e in v[. . .])

C.A. 79 r. c

Mount Caucasus the mountains of the Komedoi and the Parapanisos range are joined together between Bactria and India and give birth to the river Oxus, for it is in these mountains that it rises, and it flows five hundred miles to the north and as far to the west, and discharges its waters into the Hyrcanian sea, and it is accompanied by the Osus, the Dragodos, the Artamis, the Xariaspis, the Dragamaim, and the Margus, all very large rivers. On the opposite side towards the south rises the great river the Indus, which guides its waves for six hundred miles in a southerly direction, and while in this course it receives as tributaries the rivers Zaradrus, Bibasis, Vadris, Vandabal and Bilaspus, from the east Suastus and Coe from the west, and after having gathered these rivers into its waters it turns and flows in a westerly direction for eight hundred miles, and checked by the Arbeti mountains it makes an elbow there and turns southwards, and so after a further course of five hundred miles it comes to the Indian Ocean into which it discharges itself by seven mouths.

Within sight of the same mountain the mighty Ganges rises, and this river flows southwards for five hundred miles and to the south east for

[1] The most natural interpretation of this passage in conjunction with the topographical note and the drawing is to regard it as a record of travel. In this case Leonardo must have visited Sardinia.



CONTOUR MAP. AREZZO, BORGO SAN SEPOLCRO, PERUGIA, SIENA, VOLTERRA

Royal Library, Windsor

a thousand miles, and Sarabus, Diamuna, Soas, and Scilo with their mighty flow accompany it. It pours into the Indian Ocean by many mouths.[1]

C.A. 95 v. b

[*With drawing*]

Canal of Ivrea, made from the river of Dora.[2]

Mountains of Ivrea in their wild part; it continues towards the north.

The great weight of the barge which passes through the river which is supported by the arch of the bridge does not add weight to this bridge, because the barge weighs exactly as much as the weight of the water that the barge displaces from its position.

C.A. 211 v. a

LAKE COMO

Valley of Chiavenna

Above Lake Como in the direction of Germany lies the valley of Chiavenna where the river Mera enters the lake. Here the mountains are barren and very high with huge crags. In these mountains the water birds called cormorants are found; here grow firs larches and pines, and there are fallow deer, wild goats, chamois and savage bears. One cannot make ascents there without using hands and feet. In the season of the snow the peasants go there with a great trap in order to make the bears fall down over these rocks. The river runs through a very narrow gorge: the mountains extend on the right and the left in the same way for a distance of twenty miles. From mile to mile one may find good inns there. Higher up the river there are waterfalls six hundred braccia high which are very fine to see, and you may find good living at four soldi for your bill. A large quantity of timber is brought down by this river.

[1] MS. Comedorum. Ptolemy refers to the Komedoi as the inhabitants of the hill country that lay to the east of Bactriana.

Ptolemy is obviously the authority from whom Leonardo has derived his lists of tributaries. Those of the Oxus appear in Leonardo as Osus, Dragodos, Artamis, Xariaspis, Dragamaim and Margus, and these are given by Ptolemy as Okhos, Dargoidos, Artamis, Zariaspis, Dargamanes and Margos.

For the Indus Leonardo has Zaradrus, Bibasis, Vadris, Vandabal and Bilaspus. Ptolemy has Zaradros, Bibasis, Adris, Sandabal and Bidaspes. (See McCrindle, Ptolemy: Ancient India edit. Majumbar, Calcutta 1927.)

[2] i.e. the Dora Baltea.

Val Sasina

Val Sasina runs in the direction of Italy. It has almost the same shape and characteristics. The *mappello*[1] grows here plentifully: there are great floods and waterfalls.

Valley of Trozzo

In this valley firs pines and larches grow plentifully; and from here Ambrogio Fereri has his logs brought down.

At the head of the Voltolina are the mountains of Bormio which are terrible and always covered with snow. Here ermines breed.

At Bellagio

Opposite the castle of Bellagio is an insignificant stream which falls from a height of more than a hundred braccia from the spring where it rises sheer into the lake with inconceivable din and uproar. This spring flows only in August and September.

The Voltolina

The Voltolina as has been said is a valley surrounded by lofty and terrible mountains; it produces a great quantity of strong wine but has so great a stock of cattle that the peasants reckon that it produces more milk than wine. It is this valley through which the Adda passes which first flows through Germany for more than forty miles. In this river is found the grayling[2] which feeds on silver of which much is to be found in its sand.

Everyone in this district sells bread and wine, and a jug of wine is never more than a soldo, veal is a soldo the pound, and salt ten denari and butter the same and eggs a soldo for a quantity.

C.A. 214 r. e

At Bormio

At Bormio are the baths; eight miles above Como is the Pliniana, which rises and falls every six hours, and as it rises it supplies two mills with water and there is a surplus, and as it falls it causes the spring to dry up for a distance of more than two miles. It is in this district that a river falls with a great impetus through a mighty chasm in the mountain. These journeys should be made in the month of May, and the largest

[1] The meaning of this word is unknown. The Italian for maple is *acero*.

[2] MS. has 'il pescio temere'. I have followed Richter's suggestion 'temolo'.

bare rocks which exist in these parts are the mountains of Mandello near to those of Lecco and Gravidonia; towards Bellinzona thirty miles from Lecco are those of the valley of Chiavenna; but the greatest is that of Mandello, which has at its base a gully towards the lake that descends two hundred steps, and here at all seasons there is ice and wind.

In Val Sasina

In Val Sasina between Vimognio and Introbbio on the right hand where you enter the road to Lecco you come upon the Trosa, a river which falls from a very high rock and as it falls goes underground and so the river ends there. Three miles farther on you come to the buildings of the copper and silver mines near to the district known as Prato San Pietro, and the iron mines, and various strange things. La Grignia is the highest mountain in these parts and it is without any vegetation.

C.A. 214 v. e

WHY THE CURRENT FROM SPAIN IS ALWAYS GREATER TOWARDS THE EAST THAN TOWARDS THE WEST

The reason is that if you were to place together the mouths of the rivers which come into this Mediterranean sea you would find that there was a greater volume of water than that which this sea pours through the straits into the ocean. You see that Africa discharges into this sea such of its rivers as flow to the north, among these being the Nile which waters three thousand miles of Africa, the river Bragada, the Mauretanus and others like these. Europe pours there the Don and the Danube, the Po and the Rhone, the Arno and the Tiber. It is clear therefore that these rivers together with an infinite number of lesser-known rivers make up a greater breadth depth and current than are found in the eighteen miles of ocean straits which divide Europe from Africa at their western extremities. And if you should wish to say that the rivers which empty themselves into the ocean act differently, it is certain that the aforesaid rivers almost all have their origin in mountains near to this ocean, and if these mountains were to empty them there there would be no river in the vicinity of as great current as the Nile and the Danube, and if moreover there were a resemblance, consider that these rivers, in emptying themselves into the ocean, can give it but little increase so as to restore the current towards the east, unless it always is that the clouds contain a greater volume than that which the rivers

place there, and these clouds becoming constricted compress the air with swift movement within the other air, like a hand which squeezes a sponge with water amid the other water, so that that which flies away gives place to the rest.

Water moves within water with the same facility as air moves within air although it is more . . . [t . . .] [?] as is seen in its circles.

Current only exists in the seas which communicate with the ocean; the Caspian sea and the swamps have no current; while the Indian Ocean flows eastwards the western Mediterranean flows westward.

C.A. 215 v. d

Write to Bartolomeo the Turk about the ebb and flow of the Black Sea and ask whether he knows if there is the same ebb and flow in the Hyrcanian or Caspian Sea.

C.A. 260 r. a

OF THE CONSUMPTION OR EVAPORATION OF THE WATER OF THE MEDITERRANEAN SEA

The Mediterranean Sea a vast river interposed between Africa Asia and Europe gathers within itself about three hundred principal rivers, and in addition to these it receives the rains which fall upon it over a space of three thousand miles. It gives back to the mighty ocean its own waters and the others that it has received, and without doubt it gives less back to the sea than those it receives; for from it descend many springs which flow through the bowels of the earth and vivify this terrestrial machine. This is necessary by reason of the fact that the surface of this Mediterranean is more remote from the centre of the world than the surface of this ocean, as is proved by my second [rule]; and in addition to this the heat of the sun is continually evaporating a portion of the water of the Mediterranean, and as a consequence this sea can acquire but little increase from the aforesaid rains, and is but little diminished through the water that has been added to it being poured into the ocean, or from it being evaporated by the heat of the sun or the course of the parching winds.

C.A. 263 v. b

The watery sphere desires perfect roundness, and that part which projects above its general surface cannot continue, and in a short time becomes smooth; and if you should wish that the water should be drawn aside in order to allow space for the earth and uncover it, and that in

this way it should remain spherical, this would be impossible because the water that flows from Syria would be low, and at the island Aritella which is four hundred miles distant from the strait of Gibraltar it would be the high sea, which is three thousand four hundred miles distant from the shores of Syria, and at this island the water is very shallow, and beyond it there is little depth to be found.

C.A. 264 r. b

Amboise has a royal fountain which has no water.

C.A. 296 r. a

[*Mechanical drawings with various numbers, 'minutes of the hour', 'hours', 'moon'*]

Clock of the tower of Chiaravalle, which shows the moon, the sun, hours and minutes.

C.A. 399 v. b

Why there is water in the high parts of the mountains:

From the straits of Gibraltar to the Don is three thousand five hundred miles, that is to say one mile and one sixth, allowing a fall of one braccio per mile for all water that moves at a moderate rate of speed. And the Caspian Sea is considerably higher, and none of the mountains of Europe rises a mile above the surface of our seas. One might therefore say that the water which is in the summits of our mountains comes from the heights of these seas, and from the rivers which pour themselves down there and which are higher.

F 50 r.

[*Of sand-hills. Libya*]

Describe the mountains of 'flexible dry things'. Treat that is of the formation of the waves of sand borne by the wind, and of its hillocks and hills as it occurs in Libya; you may see examples in the great sand banks of the Po and the Ticino and other large rivers.

F 61 r.

Map of Elephanta[1] in India which belongs to Antonello the merchant.

F cover 2 r.

[1] Elephanta is the name of an island in the harbour of Bombay named from a colossal statue that stood on it and containing Brahmanic rock caves of vast dimensions which served the Hindus as temples, the largest, hewn out of hard trap rock, being one hundred and thirty feet across with columns and sculptures. The note may be due to the fact of some account of these caves having come to the knowledge of Leonardo. His interest in rock caves is shown from a passage in the Arundel Manuscript (B.M. 155 r.).

At Santa Maria at O. in the valley of Ravagnate in the mountains of Brianza[1] the rods of the chestnut are nine braccia and fourteen: five lire for a hundred of nine braccia.

At Varallo Pombia near Sesto upon the Ticino the quinces are large white and firm.

G I r.

[*Water of a mill at Florence*]

[*Drawing*] Small mill at Florence.

This water in its general descent turns a right angle; but in the floods it goes straight. And its percussion is so powerful that as it burrows down it carries the stones in its course, rolling over the strand formed by the other stones; and so the water following the leap out of its surface leaves the driven stones on the extremity of the mountain. But when the bed or the floods fail the water cannot pass the already formed hill of shingle, and consequently it turns in its first course made by the fall of the other water, which is found in excess at the fishing pool, which forms this hollow at the place where the water falls.

I 75 [27] v.

The shepherds in the Romagna make at the base of the Apennines certain huge hollows in the mountains of the shape of a horn and they set a horn by its side so that this small horn becomes one with the cavity already made and by means of it a very loud noise is produced.

K 2 r.

Rhodes contains five thousand houses.

L cover v.

[*Notes made in Romagna*]

Dove-cot at Urbino. 30 July 1402 (1502).

L 6 r.

[*With sketch of wave*]

Made by the sea at Piombino.

The water *a b c* is a wave which has traversed the slope of the shore and which as it turns back meets with the wave that comes upon it; after

[1] MS. 'Nella valle di ranvagnan ne monti brigantia'. I have followed the translation of Richter. Ravaisson-Mollien points out however that Leonardo on the following page of the MS. mentions Monte Viso, which is not far from the mountains of Briançon (Brigantio), and hazards the conjecture that there may be a locality of a name resembling ranvagnan in a valley of this region.

striking each other they leap upwards and the weaker yields to the stronger so that it traverses again the slope of the said shore. L 6 v.

Acquapendente belongs to Orvieto. L 10 v.

[*With drawing*]
Fortress of Cesena. L 15 v.

[*With drawing of bell*]
Siena. L 19 v.

[*With architectural drawings*]
Steps of Urbino. L 19 v.

The foundation must be as broad as the thickness of any wall upon which this foundation rests. L 20 r.

[*With drawing*]
Bell of Siena, that is the manner of its movement and the position of the attachment of its clapper. L 33 v.

[*With architectural drawing*]
St. Mary's Day, the middle of August, at Cesena, 1502. L 36 v.

[*With drawing*]
Stairs of the Count of Urbino — rough. L 40 r.

At the Fair of San Lorenzo at Cesena, 1502. L 46 v.

[*With drawing*]
Window at Cesena.

A for the frame of linen cloth, *b* for the window of wood; and the angle rounded off is a quarter of a circle. L 47 r.

Porto Cesenatico on the sixth day of September 1502 at fifteen hours.

How bastions ought to project beyond the walls of towns to be able to defend the outer slopes so that they may not be struck by the artillery. L 66 v.

The fortress of the harbour of Cesena is at Cesena four points to the south-west.

L 67 r.

[*With drawing*]

Grapes carried at Cesena.

The number of the men who dig the trenches takes the form of a pyramid.

L 77 r.

Make a harmony with the different falls of water as you have seen at the fountain of Rimini, as you have seen on the eighth day of August 1502.

L 78 r.

[*With plan*]

Fortress of Urbino.

L 78 v.

[*With drawing*]

Cart of Cesena.

L 82 r.

First day of August 1502.

At Pesaro, the Library.

L cover r.

[*The Arno*]

No simple reflex movement is ever as much raised as the commencement of the falling movement.

To guard against the percussion of the Arno at Rucano and to turn it with a gentle curve towards Ricorboli, and to make the bank so wide that the fall of its leap may be above it.

L 31 r.

BRIDGE OF PERA AT CONSTANTINOPLE

Width forty braccia, height above the water seventy braccia, length six hundred braccia, that is four hundred above the sea and two hundred resting on land thus forming abutments to itself.[1]

L 66 r.

[1] The time references in this manuscript point to this note as having been written in or about the year 1502. The project seems to have gone no farther. Richter records how four years later when Michelangelo suddenly left Rome he entertained the idea of going to Constantinople where, as both Vasari and Condivi state, his services had been requisitioned to make a bridge to connect Constantinople with Pera.

In Romagna where all the dullards congregate they use carts with four equal wheels, or they have two low in front and two high ones behind, and this is a great restraint on movement because more weight is resting upon the front wheels than upon those behind as I have shown in the first of the fifth 'Concerning Elements'.

And these first wheels move less easily than the large ones, so that to increase the weight in front is to diminish the power of movement and so to double the difficulty.

[*Diagram*]

Here the larger wheel *a* has three times the leverage of the small wheel; consequently the small one finds three times as much resistance and to add a hundred pounds [necessitates adding] two hundred more to the small [wheel] *a*; look how this works.

L 72 r.

[*A note on relative positions of towns between Bologna and Forli*]

Imola sees Bologna at five points from the west towards the north-west at a distance of twenty miles.

Castel San Pietro is seen from Imola midway between west and north-west at a distance of seven miles.

Faenza is as regards Imola exactly in the centre between east and south-east at a distance of ten miles.

Forli is as regards Faenza exactly in the centre between south-east and east at a distance of two miles from Imola and ten from Faenza.

Forlimpopoli is in the same direction at twenty-five miles from Imola.

Bertinoro is as regards Imola at five points from the east towards the south-east, at a distance of twenty-seven miles.

L 88 v.

From Bonconvento to Casanova 10 miles; from Casanova to Chiusi 9 miles; from Chiusi to Perugia 12 miles; from Perugia to Santa Maria degli Angeli and then to Foligno.

L 94 v.

[*With drawing*]

Solid rock of Mugnone hollowed out by the water in the form of vessels. It seems a work done with the hand, because it is so exact.

B.M. 29 v.

OF THE CUTTING OF ABYLA AND CALPE IN THE STRAITS OF CADIZ

The cutting of Abyla and Calpe in the straits of Cadiz reduces considerably the rivers which descend from the Alps and run to the north. And this is proved by reason of the fact that before this cutting in the mountains of Cadiz was formed the surface of the Mediterranean Sea was very high, and surpassed the height of three parts of the Alps, and the penetration of the sea through the passages and veins of the earth was very high and abundant; and after this cutting of Cadiz the surface of the Mediterranean Sea there was lowered, and the aforesaid high passages remained emptied of their waters, and the rivers lost the abundance of their streams.

B.M. 168 v.

[*With drawings*]

When two rivers together intersect that will be of less depth which is of slower course.

When Rifredi *b* meets with the sluggish Arno, this Arno raises its bed, and the stream of Rifredi wears it away and makes sudden depth.

B.M. 271 r.

They do not know why the Arno never keeps its channel. It is because the rivers which enter it deposit soil where they enter and take it away from the other side, thus forming a bend in the river there.

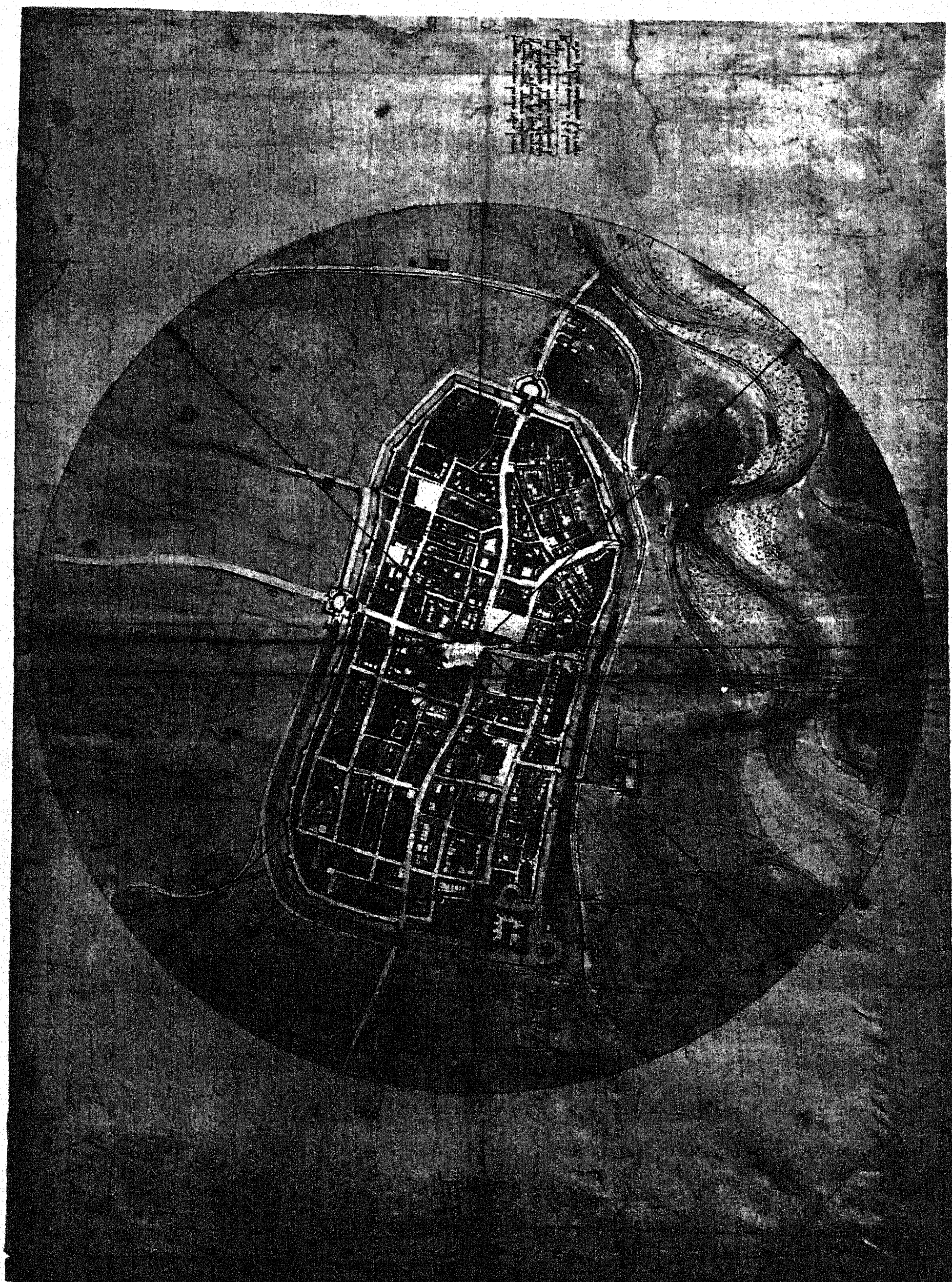
The course of the Arno is six miles from La Caprona to Leghorn, and twelve through the marshes which have an expanse of thirty-two miles, and sixteen up from La Caprona which makes forty-eight; by the Arno from Florence there is a space of sixteen miles; to Vico is sixteen miles and the canal is five; from Florence to Fucechio is forty miles by the water of the Arno.

Fifty-six miles by the Arno from Florence to Vico; and by the Pistoia canal is forty-four miles; therefore it is twelve miles shorter by the canal than by the Arno.[1]

Windsor: Drawings 12279

The direction of Imola from Bologna is five points north-west of west and its distance is twenty miles.

[1] Vasari refers to Leonardo's interest in the project of a canal from Pisa to Florence. Documents showing his activity in project of turning the Arno in war with Pisa in 1503 are given in Gaye, *Carteggio Inedito*, and by Milanesi, *Arch. Stor. Ital.*, Serie III, Tom. XVI.



PLAN OF IMOLA

Royal Library, Windsor

[Text: I. 388-9]

The direction of Castel San Pietro from Imola is midway between west and north-west at a distance of seven miles.

The direction of Faenza from Imola is exactly midway between east and south-east at a distance of ten miles, so also is that of Forli from Imola at a distance of twenty miles, and of Forlimpopoli from Forli at a distance of twenty-five miles.

The direction of Bertinoro from Imola is two points south-east of east at a distance of twenty-seven miles.

Windsorr: Drawings 12284

FOR THE SHRINE OF VENUS

You should make steps on four sides by which to ascend to a plateau formed by nature on the summit of a rock; and let this rock be hollowed out, and supported with pillars in front, and pierced beneath by a great portico, wherein water should be falling into various basins of granite and porphyry and serpentine, within recesses shaped like a half-circle; and let the water in these be continually flowing over; and facing this portico towards the north let there be a lake with a small island in the centre, and on this have a thick and shady wood.

Let the water at the top of the pillars be poured down into vases standing at their bases, and from these let there be flowing tiny rivulets.

From the coast. — Setting out from the coast of Cilicia towards the south, you discover the beauty of the island of Cyprus, which . . .

Windsor: Drawings 12591 r.

From the southern sea-board of Cilicia may be seen to the south the beautiful island of Cyprus, which was the realm of the goddess Venus; and many there have been, who, impelled by her loveliness, have had their ships and rigging broken upon the rocks which lie amidst the seething waves. Here the beauty of some pleasant hill invites the wandering mariners to take their ease among its flowery verdure, where the zephyrs continually come and go, filling with sweet odours the island and the encompassing sea. Alas! How many ships have foundered there! How many vessels have been broken upon these rocks! Here might be seen an innumerable host of ships; some broken in pieces and half-buried in sand; here is visible the poop of one, and there a prow; here a keel and there a rib; and it seems like a day of judgment when there shall be a resurrection of dead ships, so great is the mass that

covers the whole northern shore. There the northern winds resounding make strange and fearful noises.

Windsor: Drawings 12591 v.

Of the waters of the lake of Viterbo which are changed into vapour:

How the fire of Mongibello[1] is fed thousands of miles away from its mouth.

Leic. 18 r.

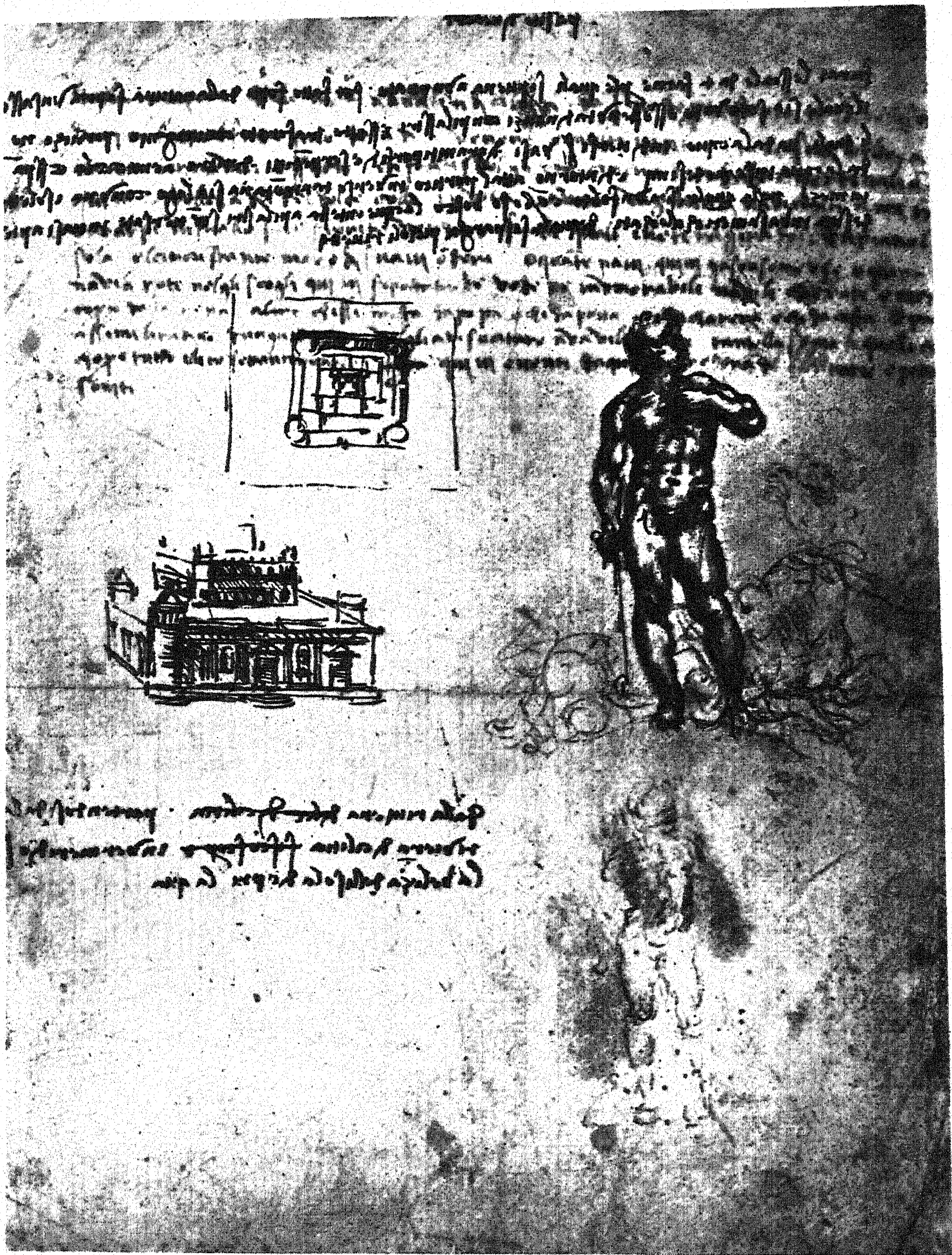
How at Bordeaux, which is near Gascony, the sea rises about forty braccia before it ebbs, and the salt waters flood the river for more than a hundred and fifty miles; and the vessels which have been laid up to be caulked are left high and dry on the top of a high hill above where the sea has receded.

How above Tunis there is a greater ebb than [elsewhere] in the Mediterranean, namely about two braccia and a half; and at Venice the fall is two braccia; and in all the other parts of the Mediterranean the fall is little or nothing.

How within a short time the river Po will cause the Adriatic Sea to dry up in the same way as it has dried up a great part of Lombardy.

Leic. 27 v.

[1] Mount Etna.



NEPTUNE, ARCHITECTURAL, DESCRIPTION OF CYPRUS

Royal Library, Windsor

[Text : I. 389-90]

XVI

Atmosphere

'The air moves like a river and carries the clouds with it; just as running water carries all the things that float upon it.'

Surface is the name given to the boundaries of bodies with the air or I would rather say of the air with bodies, that is what is enclosed between the body and the air that surrounds it; and if the air makes contact with the body there is no space to put another body there; consequently it may be concluded that surface has no body and therefore no need of position.

Surface is the name given to that which divides bodies from the air which surrounds them; or as you may prefer to say which divides or separates the air from the things which are located within it.

And if the atmosphere and the bodies which are enclosed within it are in perpetual contact and there is not any space between them, the surface being that which shows the shape of the bodies this surface has existence of itself. And if the atmosphere and the body are touching each other no space will remain there, so we conclude that the surface has existence and not space. Consequently this surface is equal to nothing, and all the nothingness of the world is equal to the smallest part if there can be a part. Wherefore we may say that surface, line, and point are equal as between themselves, and each is of itself equal to the other two joined together.

Surface is the name of that division which the body of the air makes with the bodies which are enclosed within it. And it does not partake of the body by which it is surrounded, nor of that which it surrounds; on the contrary it is the actual contact which these bodies make together.

Therefore if these bodies are in continual contact it is necessary that nothing should interpose between them, and consequently the surface, which is enclosed there, is nothing. This surface has name and not substance because that which has substance has place. Not having place it resembles nothingness which has name without substance; consequently the part of nothing not having anything except the name and not the substance this part is equal to the whole; so that by this we conclude that the point and the line are equal to the surface. C.A. 68 v. a

ELEMENT OF FIRE. MIDDLE REGION OF THE ATMOSPHERE

[*With drawing*]

The atmosphere interposed between the fire and the water participates in the water and the fire, but so much more in one than the other

as it is nearer one than the other. It follows that the less it participates in each the more remote it is from them. And this remoteness occurs in the middle region of the atmosphere; therefore this middle region is in the first stage of cold. From which it follows that that part of the cloud which is in closest contact with the middle region becomes coldest; consequently the warmth of the sphere of fire of this cloud which is the attracter and mover is of less potency, and from this it follows that the movements of the particles of moisture which form the clouds are slower; and from this it follows that, in the process of these particles of moisture rising, the nearer they come to the vicinity of this middle region the slower the movement becomes, and the movement of that which follows is swifter than it, and consequently it overtakes it. And it often happens that it strikes underneath and mingles with it and thus increases its quantity and weight. The atmosphere in consequence not being able to support it makes way for it to descend, and in doing this it strikes all the drops which interrupt its course, and incorporates many in itself, and acquiring weight it acquires velocity in its descent [. . . .]. And this is the reason why after it has penetrated the whole of the cloud in every stage of descent its pace will become slower, and there will be many occasions when these particles will not arrive at the ground. If then these particles at the highest part of their height acquire so much gravity that the weight produces a swift descent, then without doubt this movement will increase their size, inasmuch as this speed will cause it to overtake the drops which are descending below it and incorporate them in itself, and this will bring about an increase of weight at every stage of its descent.

The descent of the drops which strike together without wind will not be straight but at an angle.

This is proved by the fact that if two bodies strike one another in the air the one which is less in bulk will be diverted more from its course.

And if two particles of dew or of quicksilver varying in size become joined together each will be removed from its position and the proportion of their movements will be as that of their size.

The drop of that liquid is of the most perfect roundness which is of less . . .

Why if two spherical liquids unequal in quantity come to the beginning of contact with each other does the greater draw to itself the

lesser and incorporate it immediately without destroying the perfection of its own roundness.

It is difficult to give an answer; but I will not for this reason refrain from stating my opinion. Water clothed with atmosphere naturally desires to be united in its sphere, because in such a position it is deprived of gravity, which gravity is double; for the whole has a gravity which depends on the centre of the elements, and there is a second gravity dependent on the centre of this watery sphere, for if it were not so it would form by itself a half sphere only which is that which stands from the centre upwards; and I do not perceive that the human intellect has any means of acquiring perception of this except by saying as one says of the action of the magnet when it draws the iron, that such virtue is a hidden property of which there are in nature an infinite number.

But it may be asked why there is greater perfection in the little sphere of the liquid than in the large one. To this the reply is that the little drop has a lightness which more resembles the atmosphere that surrounds it than the large drop has, and from the fact of this small difference it is more sustained from its centre downwards by this atmosphere than the large drop. And as a proof of this, one may take as an instance the little drops which are so small in shape as to be of themselves almost invisible but which are visible when there are a large quantity together; and these are the particles which go to form clouds and mist.

Why the atmosphere when it has been submerged rises enveloped in a sheet of water. Which settles on its surface in the shape of a half sphere.

And if it is slimy water it moves through the atmosphere in the form of a sphere.

[*Drawing*] Bubble or rather vesicle of water.

You will make an experiment with these bubbles of water which over a little water set in a basin produce by means of the solar rays images of the form of a cross on the bottom of this basin.

C.A. 75 V. a

Air and fire are capable of an infinite amount of compression as is seen with mortar-pieces and thunderbolts.

C.A. 97 V. a

The body of the air is filled with an infinite number of radiant pyramids formed by the objects situated in it, and these pyramids intersecting and interweaving without displacement one of another

blend together in their separate courses throughout the whole of the surrounding air; and they are of equal power, and all have as much capacity as each one and each has as much as all; and through them the image of the body is carried all into the whole and all into a part, and each receives of itself in its every smallest part the whole cause.

C.A. 101 v. b

The movement of the thunderbolt which originates in the cloud is curved, because it bends from thickness to thinness, this thickness being occasioned by the fury of the aforesaid movement. For this thunderbolt not being able to extend in the direction in which it commenced, bends into the course that is freest and proceeds by this until it has created the second obstacle, and so following this rule it continues on to the end.

C.A. 121 r. b

Why flame does not occur except above some space where there is smoke, and why it does not strike except through its smoke. This happens because the flames as they strike the air divide in pyramids, connected by ends which curve concavely and not convexly, and air within water does the same.

C.A. 131 r. b

That the atmosphere attracts to itself like a magnet all the images of the things which surround it, and not only their bodily shapes but also their nature, is clearly to be seen in the case of the sun, which is a hot and luminous body. All the atmosphere which is exposed to its influence is charged in all its parts with light and heat, and it all receives within itself the shape of that which is the source of this heat and radiance and does the same also in each minutest part. The north star is shown to do the same by the needle of the compass; and each of the planets does the like without itself undergoing any diminution.

Among the products of the earth the same is found to happen with musk and other scents.

C.A. 138 v. b

The cloud carried by the warmth which is shut up within it thrusts itself towards [. . . .] disc of fire, comes to the cold region of the air, which is frozen on the outer side but is not frozen within, because the warmth which has carried it up there preserves it from such cold; and this brings to pass three circumstances, the first being the evaporation of the moisture which after being pent up through the cold separates

and dissolves into vapour and produces a raging wind; the second is the rain that is produced by the accumulation of the particles of moist vapour, for those of swift movement driven by the heat clash against those which are moving more slowly, and as they encounter that part of the cloud which becomes cold towards its extremities the particles of the moisture fasten themselves together and acquire weight, and so it descends to earth in big drops; and on the very extremity of this cloud the particles of moisture are continually freezing into balls of various sizes, and these cannot expand because of the intensity of the cold, but come together with swift movement at the spot where the sphericity of the drop is produced, and therefore the hail is composed of [. . . .] of many roundnesses which are joined together.

C.A. 162 r. a

The elements are changed one into another, and when the air is changed into water by the contact it has with its cold region this then attracts to itself with fury all the surrounding air which moves furiously to fill up the place vacated by the air that has escaped; and so one mass moves in succession behind another, until they have in part equalised the space from which the air has been divided, and this is the wind.

But if the water is changed to air then the air which first occupied the space into which the aforesaid increase flows must needs yield place in speed and impetus to the air which has been produced, and this is the wind.

The mist that is in the wind is produced by heat, and it is smitten and banished by the cold, and this cold drives it before it, and from where it has been driven the warmth is left cold. And because the mist which is driven cannot turn upwards because of the cold that presses it down, and cannot turn downwards because of the heat that raises it up, it therefore becomes necessary for it to proceed across, and I for my part consider that it has no movement of itself, for as the said powers are equal they confine the middle substance equally, and should it chance to escape the fugitive is dispersed and scattered in every direction, just as with a sponge filled with water, which is squeezed so that the water escapes out of the centre of the sponge in every direction. So therefore does the northern wind become the producer of all the winds at one and the same time.

C.A. 169 r. a

[*Of winds*]

The north wind comes to us from high and frozen places and therefore it cannot give off moisture, and consequently it is pure and clean, because it is cold and dry, and for this reason it is very light in itself but its speed makes it powerful wherever it strikes.

The south wind has not the same purity, and since it is warm and dry it dissolves the thicknesses of the watery vapours which the Mediterranean Sea exhales, and these then follow in the wake of this wind and become dissolved in it; and so for this reason this wind as it strikes Europe comes to be warm and damp and heavy in its nature, and although its movement is sluggish its stroke is no less powerful than that of the north wind.

Every wind is by nature cold and dry but it takes to itself as many different attributes as are those of the places through which it passes, leaving behind it in passing dampness and cold to the dry and hot places and taking from these same hot dry places their dryness and heat. So in its movement in each region it puts on different attributes, and in becoming warm and dry it weakens its power, and in resuming the things it had left behind it resumes the aforesaid forces together with them, for when there is the same swiftness of movement that thing which is of greater weight will give a greater percussion, and so conversely the lighter thing will give a less percussion.

When in summer the sun returns to the parts of Africa the humidity which had been increased there by the winter becomes dissolved and its bulk increases, and it searches in fury for places to contain this increase. And this is the south wind, which in autumn drives the maritime vapours of the Mediterranean before it, and condenses them above our regions, until they fall down again through lack of power to maintain themselves.

When many winds strive together then the waves of the sea have not a free course, but they clash together and raise themselves up and at times cause ships to founder; and in such a contest the stronger wind will be the victor through its being lighter and less interwoven or mingled with the other winds.

C.A. 169 V. a

All objects have all their images and likenesses projected and mingled together throughout the whole extent of the surrounding atmosphere. The image of every point of their bodily surfaces exists in every point of

this atmosphere, and all the images of the objects are in every point of this atmosphere. The whole and a part of the likeness of the atmosphere exists in every point of the surface of the objects which are over against it. Therefore the part and the whole of the images of the objects appear in all and in each part of the atmosphere which is opposite to them; and the substance of the atmosphere is seen reflected in the whole and in each part of the surface of these objects. Therefore clearly we may say that the likeness of each object either whole or in part is interchangeably in each part and in the whole of the objects opposite to it, as is seen with mirrors when placed one opposite to another. C.A. 179 V. C

Those winds which descending scour the parts of the mountains that lean towards the sea, penetrate to its bed and make waves, with sides that resemble the shores from which they descend, and these waves consequently have often deep narrow spaces between them, as I said in the book on the movement of water. And this tempest lasts only a short time after the stroke of the wind, for after it has struck it leaps back into the air until it finds the other wind, and striking against this it compresses it and again leaps downward after the manner of the rivers as they strike the shores.

On the summits of the mountains the wind is of great density, and in the mouths of the valleys when the mountains which shut in these valleys are of great height. The entry of opposite winds one beneath the other with contrary movements may occur for two reasons, namely either through the reflex movement of the wind which turns back after having struck upon the mountains, or by the clashing together when the weaker parts of opposing winds strike against the stronger parts. The revolutions or eddies of the winds are born in the winds as they open out in the embrace of the mountains or of some building, and afterwards join together and strike with impetus; and their reflex movements are not made in a straight line, for it is checked in its own sphere, being moved by a substance like itself which has the power to check and bend its direct impetus. So therefore this wind not being able to extend proceeds to exhaust its impulse by a [curving] movement, and goes upwards in order to consume its impetus, this being necessary for three reasons; firstly because it cannot at once turn on the very lines of its descent, secondly because they strike at angles less than right angles, and because they cannot leap back on lines equal to those of their incidence.

C.A. 180 V. a

[*Cloud, wind and thunderbolt*]

As water flows in different directions out of a squeezed sponge, or air from a pair of bellows, so it is with the thin transparent clouds that have been driven up to a height through the reflection occasioned by the heat, the first part which finds itself uppermost being that which comes first to the cold region, and here remaining through the cold and dryness awaits its companion. That part below as it ascends towards the part that is stationary treats the air which happens to be in the centre as though it was a syringe, and this then escapes crosswise and downwards, not going upwards because it finds the cloud so thick that it cannot penetrate it.

So for this reason all the winds that make war upon the earth's surface come down from above, and as they strike upon the resisting earth they produce a movement of recoil, and this as it desires to raise itself up again to a height finds there the other wind, which descends and subdues its ascent, whereby the said upward movement is constrained to break its natural order, and taking a transverse route it pursues a violent course which grazes incessantly the surface of the earth.

And when the aforesaid winds strike upon the salt waters the form is clearly visible, in the angle that is created by the line of incidence and that of the recoil from which proceed the proud menacing and engulfing waves, of which the one for the most part is the cause of the other.

Here someone perhaps may think to censure me by putting forward as against my contention as to the winds the argument that these cannot be produced by the clouds because then it would be necessary for one to remain stationary and give movement to another, and this does not appear to be so, because when the north wind blows the clouds all collect together and fly before it. The reply to this is that when the air is still and a full company of clouds have risen to a height, and there above as has been said press themselves together, they squeeze out so much air from themselves, which through the violence exerted creates such movement in the air, that as you may see it communicates its movement to the other lesser clouds. And as they also drive the air forwards in the same way they even furnish themselves with a reason for greater flight; for when a cloud either finds itself in the midst of others or apart from them, if it produces the wind behind itself that air which is between it and its neighbour following comes to multiply, and by multiplying acts in the same way as the powder does in the mortar, for this expels from the position near to it the less heavy body and the lighter weight. And

this being the case it follows that the cloud in driving the wind towards the others which offer resistance is the cause of putting these themselves to flight. And by sending this vanguard of the winds before itself it also adds volume to the rest. And if it should send them crosswise it would form a kind of rotatory circle around some cloud and then return in concert with the others.

As the natural warmth spread through the human limbs is driven back by the surrounding cold which is its opposite and enemy, and flowing back to the lake of the heart and the liver fortifies itself there, making of these its fortress and defence, so the clouds being made up of warmth and moisture, and in summer of certain dry vapours, and finding themselves in the cold dry region, act after the manner of certain flowers and leaves which when attacked by the cold hoar-frost press themselves close together and offer a greater resistance.

So these in their first contact with the cold air commence to resist and not to wish to pass farther forward; the others below continue constantly to rise, the part above being stationary proceeds to thicken, the warmth and dryness recede to the centre, the part above abandoned by the warmth commences to freeze or to express it more exactly to dissolve, and as the clouds below continue to rise their warmth is brought nearer to the cold and so being constrained to reduce itself to its primary element is suddenly transformed into fire, and this twines itself among the dry vapour and in the centre of the cloud makes a great increase, and as it kindles itself within the cloud which has become cool it makes a noise that resembles that of water falling on boiling pitch or oil, or of molten copper when plunged into cold water. Even so driven forth by its opposite it shatters the cloud that would withstand it, and hurtling through the air breaks and destroys everything that opposes it, and this is the thunderbolt.

C.A. 212 V. a

The air is compressible to infinity, and this is shown by the extremely swift movement of the radiance which produces the mighty thunder of the heavens, which bends and twists itself in different directions so much the more as the air and cloud before it is compressed and . . .

Example of thunder

The process of evaporation of water thrown upon burning coals is as that of the fire when kindled among the clouds which evaporate with

such fury as to restrict the course of the brightness that has been created; that is to say that as the water is changed into vapour and becomes steam as it increases so the cloud evaporates and becomes changed into air, which by its increase hems in and restricts the flame which is produced in it.

C.A. 213 r. a

Flame has its beginning and end in smoke.

The smoke out of which the flame is produced is of much greater heat than the smoke in which this flame ends, because in the first smoke there is the nascent power of the flame, and the last is the dying away of the same flame.

Wood that is young and dry will produce smoke of a more intense blue than wood that is old and damp.

. . . . .

The blue flame which is midway between the darkness and the light comes into being between the nutritive portion of the candle and its flame, and is of greater heat and radiance than the smoke and of less heat and radiance than its flame; and the vapour cannot transform itself into flame, without first becoming changed to this blue colour, and this is known in the case of smoke.

Flame is condensed smoke, formed out of the meeting together of the air that is in this blue smoke, which . . .

The blue smoke is the transit of the material nutriment that is the grease that is in the candle. The white smoke that surrounds the vestige of the flame is the spiritual transit of the flame of this candle, which in its lowest part is mingled with the topmost part of the aforesaid blue smoke, and in the upper part is mingled with the smoke which proceeds from the flame of the candle.

C.A. 237 v. a

Write why the campanile shakes at the sound of its bells.

C.A. 242 v. a

The southern winds are more powerful in the northern than in the southern regions and in summer than in winter; and this is because the sun dissolves all the moisture that rises from the Mediterranean Sea, which cannot dissolve during the cold of winter, and of these vapours few rise and these few are dissolved in water. But when the sun passes beyond the circle of the equinox, and it is winter here at hand and summer over yonder the sun dissolves all the vapours as they rise, so that

they glide in aerial waves as far as the chief [mountains] of Europe, and there coming upon the cold in the autumn they turn into rain, and in the winter they are knit together in snow, and fall in snowstorms and so proceed little by little to stifle the breath of the aforesaid winds.

C.A. 246 v. a

Where flame cannot live no animal that draws breath can live.

Excess of wind puts out flame, moderate wind nourishes it.

C.A. 270 r. a

[*Of flame and wind*]

The bottom part of the flame is the first beginning of this flame through which passes all its nutriment of fat; and this is of so much less heat than the rest of the flame as it is of less brightness; and it is blue in colour and is the part in which its nutriment is purged and disposed of.

That has the brighter flame, and this is the first to come into existence when the flame is created, and it comes into existence in spherical shape, and after a span of life produces above itself a very small flame, radiant in colour and shaped like a heart with its point turned to the sky, and this proceeds to multiply continuously on towards infinity, by means of its acquiring possession of the substance that feeds it.

The blue flame is formed of spherical shape because it is not of such great heat as exceeds the lightness of the air; and for this reason it does not in itself form a pyramidal figure, but remains in spherical shape until it has warmed sufficiently the air which surrounds it, and because the chief warming of the air is above the principal heat of this blue flame, this heat being produced by that part where the natural desire of the flame is to move itself, that is to the sphere of fire by the shortest way. Therefore the fire comes into existence in the upper part of the blue spherical flame, in a small round figure, the roundness of which immediately undergoes some extension and assumes the shape of a heart, of which the point is turned towards the sky. And this shape immediately and with swift dilation overcomes the power that feeds it, and penetrates the air which serves it as a covering. But this blue colour remains in the base of this flame as may be seen in the light of the candle; and this comes to pass because in this position the flame is always less warm than elsewhere, because there is the first encounter which provides the nourishment of the flame with this flame, and it is there that the first

heat is produced, and this is feebler and causes less warmth because it is only the commencement of the heat....

That wind will be of briefer movement which is of more impetuous beginning; and this the fire has taught us as it bursts forth from the mortars, for it shows us the form and speed of the movement in the smoke as it penetrates the air opposite to it in brief and spreading revolution.

But the impetuosity of the wind is fitful, as is shown by the dust that it raises in the air in its various twists and turns. One perceives also in the chains of the Alps how the clashing together of the winds is caused by the impetus of various forces. One sees also how the flags of ships flutter in different ways; how on the sea one part of the water is struck and not another; and the same thing happening in the piazzas and on the sandbanks of the rivers, where the dust is swept together furiously in one part and not in another. And since these effects give us experience of the nature of their causes we can say with certainty that the wind which has the more impetuous origin will have the briefer movement, from the experience that has been referred to above as to the brief movement of the smoke from the mouth of the mortar. And this arises from the resistance that the air makes on being compressed by the percussion of this smoke, which also itself, as has been seen clearly shows compression when it offers resistance to the wind. But if the wind is of slow movement it will extend a long way in a straight course, because the air penetrated by it will not become condensed opposite to it and thus thwart its movement, but will readily expand spreading its course over a very great space.

OF EDDYING WINDS

When a wind has been divided by mountains or other erections, if on coming together again it should assume the shape of a rectangle, the movement which it makes after this reunion will be of a rotatory nature in the shape of a twisted column; and if the winds which are thus reunited should be equal then this column will not change its position; but if the winds are unequal the column will move in the direction of the weaker wind.

C.A. 270 v. a

Fire or other heat lightens moisture and makes it lighter than the air; for which cause this moisture rises to the middle region of the air,

and finding there the maximum cold of the air, the fire or heat infused through this cloud flies towards the centre, and there becoming strong separates the moist vapour from the dry, and it is for this reason that the fire becomes kindled there and turns into steam a great part of the moisture which is round about this fire. And this process of vaporisation as it increases restricts the fire, and the fire thus restricted acquires potency and bursts through the cloud in the part in which it is weakest, and forms a gate for the movement of the thunderbolt and the wind.

Whether the wind is caused amid the air, and cannot make any movement unless it is supported in the place where it resists by the opposite side of the movement, as is seen to be the case with the rays driven by the fire, for through the percussion that the fire makes in the air which offers some resistance to it, these fly more slowly than this fire; and if this were not the case such ray would be without movement.

Further we may say: the wind moves in a straight line and not as Aristotle would have it in a circular line; and this we learn from the movement of a storm at sea when there is no wind, for it is a sign that such wind follows its straight line leaving below it the curve of the sea.

Why the clouds are formed with various round shapes which are separated at different spaces one from another:

The movements of the air spring from the dispersal and collection of moisture.

Heat separates and disperses and cold assembles and freezes or condenses.

C.A. 279 r. b

OF THE DROPS THAT FORM IN THE AIR

Drops are formed in the air through the mists or clouds by various movements, as when they encounter each other and become condensed or unite in the movement of the same cloud in the same direction, when one part of the cloud is swifter or slower than the other; for as the swifter part is behind the slower it conquers it in its course and overtakes it, and condenses it and out of many small drops makes one large one, and this acquires weight and falls. But unless the drops are so formed as to be of considerable size they are consumed by the friction they make with the air as they traverse it.

C.A. 292 r. a

The moist wind which is found in the caverns that have both entrance and exit can produce water, and this especially when these caverns have

twisted and shapeless sides; but this production of water is not permanent in its effect for when the wind is lacking the supply ceases, and if a contrary wind should enter by the opposite mouth of this cavern the water which bathed its walls will become evaporated and changed into air; and if this cavern have an entrance but no exit the moist wind which strikes its mouth could not enter there unless the air within that filled it were expelled. And since two opposite movements cannot penetrate each other it must needs be that the air that dwells within the cavern will find it easier to be condensed than to escape, and for this reason it will resist the entrance of the wind which beats upon it. C.A. 296 v. b

The images of every visible object are all infused in all the air over against them, and are all separated in every part of the same air.

The images of objects which confusedly as they mingle fill with themselves the air over against them are all in all this air and all in every part of it. C.A. 345 r. b

Every body situated within the luminous air fills the infinite parts of this air circle-wise with its images, and it is all in all and all in the part, and goes lessening its images throughout the equidistant surrounding space like a . . .

Of the four elements and two . . .

1. The stone thrown into the water becomes the centre of various circles, and these have as their centre the spot which has been struck.

2. And the air in the same way is filled with circles, the centres of which are the sounds and voices formed within them.

How the various circles of the water form round the spot which has been struck by the stone.

The stone where it strikes the surface of the water creates circles round itself which proceed to expand so much that they die away; and the air also when struck by a voice or a noise departing circle-wise in the same way proceeds to lose itself so that the nearest perceives better, and the more distant hears less.

COMPARISON OF HOW THE THINGS COME TO THE EYE

Just as the air struck by the voice, the water by the stone proceed in circular movement revealing their cause, and these circles make their

centre in the place which has been struck, and the farther away they proceed from it . . .

C.A. 373 r. b

The fifth essence is infused through the air as is the element of fire, although each of these may have its reason in itself or through itself; and since each particle is supplied with nutritive matter it acquires growth and increase of form; and if the nourishment be taken away from them they suddenly abandon this body and return to their first nature.

C.A. 393 v. a

The air is all in all and all in its image in the part set over against it.

If within the air there be no opaque body the whole of it has a capacity which extends over the whole and over the part, and the part has a capacity which extends over the part and over the whole.

Therefore we may say that the air is all entwined in all of it, and is filled with the infinite rays of the images of the bodies which are situated within it, and this air is full of an infinite number of points, and every point is indivisible, and the parts of this indivisibility of all the images of the parts of bodies set over against them have capacity, and in these points they are entirely united and entirely divided and separated without confusion the one from the other.

And the pyramids of the images are spread throughout the whole of this air without occupation of space the one of the other, and each for itself, and are all divided through all and united through all.

And although the images approach the eye in the form of pyramids the eye is not conscious of this unless it forms a pyramid opposite to the thing seen.

C.A. 396 r. b

Just as the stone thrown into the water becomes the centre and cause of various circles, and the sound made in the air spreads itself out in circles, so every body placed within the luminous air spreads itself out in circles and fills the surrounding parts with an infinite number of images of itself, and appears all in all and all in each *smallest* part.

A 9 v.

OF COLD

I say that cold proceeds from two causes; the first is from the air being deprived of heat; the second is from the movement of the air. The air of itself is cold and dry and it is void of all matter or vapours, and it changes readily or to put it more exactly steeps itself in the nature

and image of the things which touch it and which it has opposite to it. As regards things that touch it, when a pungent thing such as musk or sulphur or some other powerful odour touches it it instantly permeates it; also if a luminous body be placed within it the whole of the surrounding air will be lit up.

Now to return to this question of cold I say that just as the many rays of a concave mirror converging at one point produce an extreme of heat even so many bellows blowing on the same point produce an extreme cold.

A 20 r.

[*Concerning visibility*]

Men naturally if they wish to know whether the rain has commenced look in the air that is between the eye and some dark place; and then the fine threads which the minute drops of water cause to appear in the air being lighted up are easily visible against a dark background. But men reckon the threads which are near at hand and first as though they were the last and almost touched the dark place, not perceiving that this dark place is sometimes so remote that it would not be possible to be able to see a neighbouring tower there.

C 5 v.

The colours of the middle of the rainbow mingle with each other.

The bow itself is neither in the rain nor in the eye that sees it, although it is produced by the rain, the sun, and the eye.

The rainbow is invariably seen by the eye which is situated between the rain and the body of the sun, and consequently when the sun is in the east and the rain in the west the rainbow is produced upon the western rain.

E cover I v.

OF THE POWER OF A VACUUM FORMED INSTANTANEOUSLY

I saw at Milan a thunderbolt strike the Torre della Credenza on its northern side. It travelled along it with a slow movement and then all at once parted from the tower and carried with it and tore away a part of the wall, three braccia in breadth and length and two in depth. The wall was four braccia in width and was built of old bricks which were thin and small. It was torn away through the vacuum caused by the flame of the thunderbolt. I have found traces of the same power in the

rocks of the high Apennines and especially in the rock of La Vernia. The same thing occurs with a cannon in the vacuum left by the flame.

E I r.

Which will darken the earth more? A thick dark cloud that comes between the earth and the sun, or a quantity of water equal in bulk to the said cloud, the cloud touching the ground as does the water?

F 46 v.

[*Of fire and light*]

Fire would increase to infinity if the wood were indefinitely increased.

The light of the candle will be proportionately less as it is placed in a colder spot.

F 56 r.

OF THE WIND

The air moves like a river and carries the clouds with it; just as running water carries all the things that float upon it. This is proved because if the wind were to penetrate through the air and drive the clouds these clouds would be condensed between the air and the moving force and would take a lateral impress from the two opposing extremities, just as wax does when pressed between the fingers.

OF THE MOVEMENT OF AIR

Air moves when it is drawn away to fill a vacuum, or driven by the rarefaction of the humidity of the clouds.

G 10 r.

[*Reflex course of wind and water*]

The reflex wind as it turns back upon its course subdues the oncoming wind until this reflex wind becomes enfeebled, and then it regains its force when it becomes joined with the falling movement; and such power springs from its condensation acquired at the place of the percussions, which condensation always penetrates into the falling wind up to the point at which it becomes separated and its speed of movement becomes less.

The water does the same; not however by condensation but because it rises in the air and acquires weight.

G 69 r.

Why do the northern winds commence to blow at the winter solstice, and continue until melancholy January?

At the winter solstice, that is at the middle of December, the northern winds are at their maximum strength.

G 91 r.

HOW THE WIND THAT STRIKES THE CLOUD ON ONE SIDE MAKES IT TURN ROUND

If the wind strikes the cloud on one side only, then although its opposite side, that is of the clouds, is in the motionless air, this cloud will be driven forward and turned round, and it will make a circular movement like that of the wheel of a mill turned by the water.

WHAT IS THE CAUSE THAT MAKES THE CLOUDS INCREASE THEIR HEIGHT?

When the movement of two contrary winds brings two clouds to strike together these clouds then become incorporated in each other, and not being able either to expand or lower themselves because of the wind passing beneath them, these clouds extend in that direction in which their passage is least impeded, that is upwards.

OF THE MEETING OF TWO CLOUDS MOVING DIFFERENTLY IN THE SAME PATH

When with the same wind two clouds meet together, the greater in order to have part of the more powerful wind covers the smaller; and the two become condensed at their common contact, and this causes rain.

G 91 v.

If the wind is created by excess or dearth the southern parts which separate the humidity drawn to them come to condense themselves, and not being able to receive such multiplication they drive it back; it is then drawn by the vacuum created in the cold region where this humidity becomes contracted in forming clouds, or in the southern parts where the other clouds are formed.

OF THE SWIFTNESS OF CLOUDS

The course of the cloud is less swift in itself than its shadow which moves over the earth. This is proved: — Let *e* be the solar body, *a* the cloud, and *c* its shadow: then as the cloud moves from *a* to *b* the shadow will move from *c* to *d*, from which it follows that as the shadows that pass from the earth to the cloud are made by lines that converge in the

centre of the sun, we may say by my fourth [rule] that what is set forth is true, for this fourth says: — the equidistant sections at the angle of the two converging lines will be so much less as they are nearer the place of meeting; therefore as the clouds are nearer the sun than their shadow there can be no doubt that the shadow will travel a greater distance over the earth than the cloud does through the air in the same time. G 92 v.

The atmosphere is blue because of the darkness which is above it, for black and white together make blue. H 77 [29] v.

The part of the cloud which is nearest to the eye will seem swifter than that which is higher; and for this reason they often appear to be moving in contrary directions, one to the other. H 89 [41] r.

Of the shapes that one element assumes as it penetrates into another:

Air falling from fire will turn the mill as fire issuing from air will, and in the same way air falling from water as water from air, and as earth falling from water; and you should describe the equality of the powers and resistances and the shapes that they assume as they pass.

I 76 [28] v.

[*Compressed air in rose-water at barber's*]

Whether air can be compressed in itself is shown by the barber's vessel for supplying rose-water, in which it is doubled.

Fire is quadrupled by the force of the place where it cannot increase.

I 133 [85] r.

OF THE RISING OF THE WIND

Every movable thing continues its movement in the shortest way and either shuns the obstacle or is bent by the obstacles; therefore the wind curves in penetrating the thick air, and bends upwards towards the light air. K 113 [33] v.

OF WATER AND AIR

Air that moves with impetus within the other air is compressed within itself as is shown in the expansion of the solar rays; for if the wind moves their atoms in various revolutions you see these atoms form themselves into marbled waves after the manner of watered silks or camlets (gianbellotti); and that which you see done to these atoms is done by the air which bears them shut up within itself.

The water in such cases cannot become compressed, and having all these like movements in its body it is necessary for it to drive the other water from its place, so that they may all appear on the surface.

L 78 r.

When the sun strikes upon concave mirrors and leaps back from them with pyramidal course, that part of the pyramid will be proportionately as much warmer than its base as it is less in size, and it does so in as much as its moisture becomes restricted. The hot steam which is mingled with it becomes so much more powerful as it is more united, and as it is confined within a less space it generates more heat. Consequently it often catches fire and increases, forming itself into a thunderbolt out of the cloud; and so it bursts the cloud with devastating lightning and thunder. The little particles of water, when the cloud has been contracted by the cold, fasten themselves together and fall by reason of their weight. And in this way the clouds break up, and so they return in rain to the low position.

B.M. 57 r.

The surfaces of transparent and polished bodies always mirror the objects which look upon their surfaces and are looked upon by them.

Therefore that which stands underneath the water is mirrored in the surface of the air which borders upon this water, and that which is in the air is mirrored in the surface of the water which borders upon this air.

B.M. 196 r.

The course of the winds changes and follows the movement of some other wind by reason of the mouths of the valleys which it enters and issues forth from, and this happens more with the low winds than with the high ones, and this it does from its being flexible and able to be bent in any direction except that directly opposite to its course. And desiring to move and to give place to the new wind it has to do as does the water that enters a pool by a line and then turns in various channels, but more by the line that follows that of the movement it makes at its entrance, and less by that farthest away from this entrance.

The wind is condensed above the places where it strikes, and more in the summits of the mountains than on the sea coasts visited by it; for there gather all the reflex winds, that is on summits of the straight sides of the mountains where these winds strike; for they do not extend all crosswise following the shape of the summit of the mountain, but many proceed up in a straight line and especially those that strike nearest the

bases of the mountains, although after they are above the summit of the mountain they describe a curve, and after such process of curving straighten themselves into the course of the other wind which struck them and which first made them describe a curve. B.M. 276 r.

OF THE WIND

Many are the times when the course of one wind is diverted into that of another, and this arises from the percussion which they make at the meeting of their courses when as they are not able to penetrate one into the other necessity constrains them to leap back in opposite directions.

If however the said winds are not of equal power one with another their reflex movements will not follow the movement of their striker, but the angle of percussion of the more powerful will be as much greater than that of the less powerful as is the excess of the greater power over the lesser.

Winds which blow in the same direction may be simple or mixed with other winds, that is along one part of its side the wind may be all taut because the free wind strikes it and leaps back at equal angles, but never opposite to its source because it would have to re-enter into itself and the movement of two bodies cannot penetrate within themselves. Therefore it follows that the part of the greater wind which is struck by the lesser wind would turn backwards and follow the course of the lesser wind which has struck it, but it encounters it along the remainder of its width and this causes it to curve gradually until finally it has changed back to its former course.

The same wind therefore in striking produces within itself different movements and different degrees of power, for the part of its breadth before mentioned which drives before it the part which flies away also takes a reflex movement upon the wind which it strikes, and so after it does the part which when struck puts to flight the second; and the fourth which strikes the third in such a way that in these parts it becomes denser. But the first density is greater than the last, after the manner of two streams of water striking together, as I have demonstrated in the fourth of the seventh of the elements of mechanics, for there is an angle formed at the place of the first percussion which makes the water that first strikes leap up more than any other part of it. B.M. 276 v.

[*Movement of the winds*]

If the movement of the winds proceeds from Jupiter the cause of

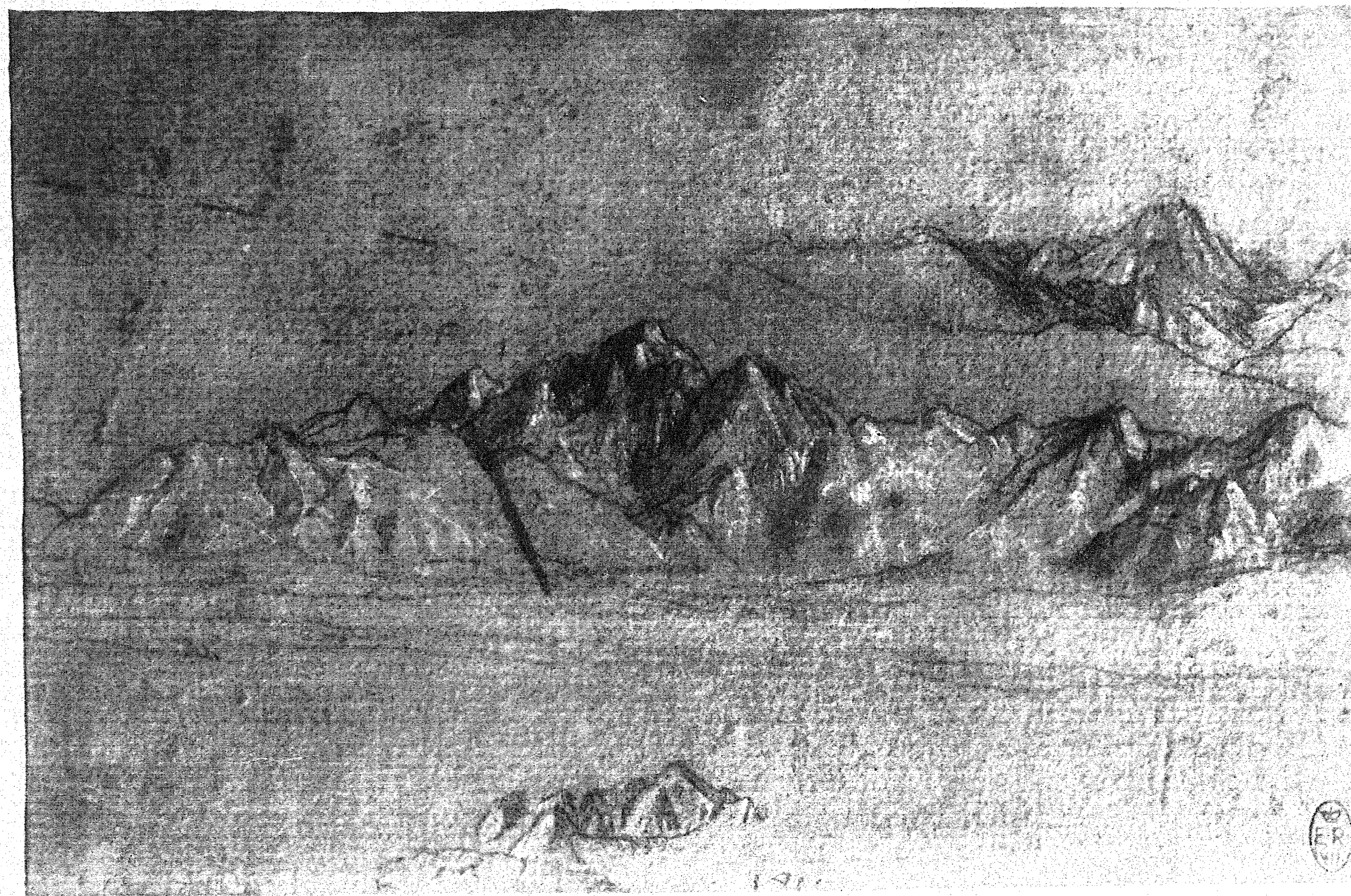
the wind must be in the twenty-four hours during which the movement of Jupiter is from the east to the west and not from the north to the south; and this arises from the fact that a thing moved by something else has the form and time of the movement of its mover. Quaderni II 20 v.

QUESTIONS: THE MATERIALS WHICH PRODUCE WIND

If (the wind) is a vapour of the earth and of cold and dryness, and is carried by heat, it rises to the cold region of the air, and, abandoned by heat, its conductor, it remains there. Such is the reason why the vapour, being similar to the vapours in that place, that is to say cold and dry, leaves the place and vapour, and flies from its similar; and this, indeed, having ceased its upward movement and entering a place entirely similar to itself is free to remain without motion. And yet if you concede it its movement, it must still move in the cold region by itself. But we shall say that such a vapour being cold and dry in its slow and late birth, becomes successively mixed with the hot, and so with a gradual expansion it generates an almost imperceptible motion in proportion to this expansion. But the motion of the heat which carries it upward is swift and so conducts it as far as the cold region of the air, where, having expelled the first part, the heat which conducts it there leaves it there, and so diminishes the vapour, which being without wind by the same amount as that of the heat which was mixed with it, being thus diminished in quantity, grows in weight above the air which sustains it, and so descends below the other vapour, and having descended there the heat which is divided from it is reunited with the heat and with the other vapour; and this giving it an upward movement and so raising all the vapour little by little it chills the upper part which penetrates the cold; and so little by little it falls back through the weight it has acquired, in such a way that the whole is composed of a greater weight than it was formerly. Hence it descends in the form of clouds, and approaching the heat refracted by the earth warmed by the sun, it becomes dissolved and dilates with great movement; and this is the wind.

The winds descend from above to below at various angles, and, striking the water or the earth, set up lateral movements along various lines, as does the water which penetrates other water.

You say that the movement of an effect follows the movement of its cause; and then say that the twelve signs of the Zodiac are the cause of the motion of winds, and that the three fiery signs, the Ram, the Lion



STUDY OF ALPINE PEAKS

Royal Library, Windsor

and the Archer are of the east and move the eastern winds; and that the three cold and dry signs, the Bull, the Virgin and the Goat move the southern winds, and the other three signs move the western winds. This theory leaves the inventor of such causes in confusion from the first proposition which you agreed on, viz. that all bodies in motion follow the movement of their motive force. Now these signs of the Zodiac are moving from east to west and go round the world in twenty-four hours. How then do you account for the fact that these signs which move towards the west will move the western winds; and yet these winds should move towards the east which would be contrary to the motion of their motive force? This is contrary to your first assumption, which is true, but your consequent theory is false.

You say that the vapour which generates the wind is carried upwards by heat and pressed down again by cold; which having been said, it follows in course that this vapour, finding itself between two contrary motions, escapes to the sides; and this lateral movement is the wind, which has a tortuous movement because it cannot descend to the earth because the heat pushes it up, and it cannot move very high up because the cold presses it down; hence this necessity gives it a latitudinal and tortuous movement. Now many drawbacks will follow from this theory of yours, of which the first is that the wind will never descend to the plain, and secondly that the cold in being driven down by such a vapour would be acting contrary to its inert nature.

Windsor: Drawings 12671 r.

Then again, it is possible that the vapour which collects in the cold region, through being abandoned by the heat which conducts it there, comes to be compressed and makes itself larger (heavier?); and the air which formerly sustained it no longer resists it, and in consequence gives place to it; and this vapour being heavy descends rapidly into the hot region near to the earth. There it is entirely permeated with heat and in consequence completely dilated and resolved, and moves in every direction which is round about it, and strikes the sea on its surface. And here one can see the cause of the origin of such wind as makes the movement of the sea, for it is flying from the first place it struck. And in this cause (case?) the courses of the parts of this wind are not parallel because they move from the centre to the circumference in direct lines.

The congregation of humidity scattered through the air, which

comes together for the creation of clouds, creates wind in the air. And similarly the breaking up of the clouds makes the fine and penetrable humidity through the air; and this is the wind. The proof: one may see the water churned up on a fire which makes a wind in the chimney that is above this fire; and again, boiling water which is shut into vases escapes through little vents of such a vase with great force in the manner of wind. And again, fires made in small rooms suck in the air through little cracks in the windows with great force and noise.

Windsor: Drawings 12671 v.

The force inherent in moving bodies has the result that movement is often contrary to the nature of the thing moved.

You say that the vapour of the wind is driven up by the heat which lifts it and is then pushed down again by the cold which joins with it; and yet necessity gives it a lateral and a curved movement, since being enclosed between two contrary forces it flies out sideways all over the earth.

But this theory denies that the vapour which has been mixed in the cold region of the air is pushed down by this cold, because it is necessary to say either that the vapour flies before the cold from its nature, or that the cold really removes it of itself, which is being contrary to the nature of the vapour. And if such a vapour moves of itself, it does so after it has increased and not before, because at first it is the power of the heat pressing it down which makes itself greater than the power of the vapour which wishes to descend. Here it must be confessed that such a vapour in increasing acquires weight, and that with this weight it overcomes the force of the heat which sustains it, and that here cold does not press it down because, if it were natural to such cold to press it down, it would have been easier to expel it when the vapour was small in quantity and weak than when it was increased in quantity and in force. And so here we shall say that the vapour of the wind, having reached the cold region, stops there, because the heat which has conducted it to this place becomes consumed in cold; and the heat being consumed the vapour remains without motive force, and so it stays there and awaits the parts which succeed and adjoin it. And these not being at such an altitude are not yet completely deprived of heat and in consequence of movement; and so not being stationary they move until at last they arrive at the same altitude as the part which has been chilled and they penetrate this and unite with it, and the heat being there condensed leaves it [the

vapour]. And so subsequently rising, one part after the other, and penetrating the higher part, they are prevented from condensing, and from that weight of such a nature that the lower region cannot sustain it above itself. Hence by necessity it descends united with it until the heat makes it light and again lifts it upwards, and does the same as it did the first time, and so once more joining with the cold part it again acquires weight and again sinks down and again turns to vapour in the upper air. And so this would go on continually and from this arises the motion of the wind spreading itself from high to low and not from here to there [vertically and not horizontally]. Well then this theory given above is false, because experience shows itself in disagreement.

You say that the winds begin by being weak and go on growing in strength, because in the beginning there was a small quantity of vapour generated by a small blast; but when such a vapour was increased in a greater quantity, being struck by the cold, it descends with greater force and from this arises the growth of wind. To this we answer that any movement is born of a void or a deficiency. If vapour which is raised by the heat, which though it penetrates the said heat, dissolves such a vapour and makes a movement sideways or rather upwards because that is the true [direction] of the movement of fire, and when, the more this evaporation rises the more it is pressed in, its exterior moves itself inwards towards the centre of the bulk. And this second movement is contrary to the first, because the first moved from the centre to the extremities and the second movement is from the extremities to the centre, and from one to the other the movement is more rapid in proportion as it is more remote from the centre, because the extremities are more affected by heat and cold than are the parts which are near the middle. But to return to the matter in hand; the more the vapour rises the more it is pressed in because it grows nearer to the cold, the exact opposite of the heat which conducts such a vapour and presses it in.

This cannot make wind which flows from it, but can make it if it runs contrary to it because it does not allow a vacuum, and the place from whence its parts are flying would remain a vacuum if the air did not fill them up, and this air rushes to fill up [the vacuum] with the same speed as the vapour when it is rushing away from the cold. And since the material joined with the motive force which moves it, moves itself in the same amount of time as the movement made by this motive force, therefore here the vapour will move itself in such time as the fire, its

first motive force, accompanies it, and when the fire is parted from it the vapour loses its movement which [movement] the cold does not give it if it is not against the half of its quantity (?), or it may be that that part of the vapour which touches the cold first of all is the first to rush backwards towards the centre, but one cannot classify this as actual flight but as the loss of its elevation.

You say that the wind does not blow continuously, but with various gusts divided one from the other; and the cause of this is the vapour which rises to the cold carried by heat in various quantities. Here one may answer that the cold does not expel the vapour but (that this is produced); but that the heat which is escaping from the cold brings back the vapour which it formerly carried with it to the cold regions. And again one may say that the heat, in the first contact which it makes with the cold, warms this cold in proportion as it touches it [the cold]; and similarly the cold chills the heat in proportion as it receives it [the heat] into itself. Hence there arises a storm; which has the result that the heat and cold lose some of their original force; and in this case the way is prepared for the transformation into vapour which succeeds, together with the heat, in penetrating more deeply into the cold and warming it to a greater altitude. And so the vapour penetrates farther in such a way that it passes through the cold region and penetrates towards the element of fire [the source of heat]; and being united with it the vapour makes a great outburst through all the surrounding regions, which outbursts are rapid movements in direct lines and result in a flood of air which [strikes] the sea above the horizon and proves to be the cause of your solution.

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OF THE COLOUR OF THE ATMOSPHERE

I say that the blue which is seen in the atmosphere is not its own colour, but is caused by the heated moisture having evaporated into the most minute imperceptible particles, which the beams of the solar rays attract and cause to seem luminous against the deep intense darkness of the region of fire that forms a covering above them. And this may be seen, as I myself saw it, by anyone who ascends Mon Boso (Monte Rosa), a peak of the chain of Alps that divides France from Italy, at whose base spring the four rivers which flow as many different ways and water all Europe, and there is no other mountain that has its base at so great an elevation.

This mountain towers to so great a height as almost to pass above all the clouds; and snow seldom falls there, but only hail in summer when the clouds are at their greatest height; and there this hail accumulates, so that if it were not for the infrequency[1] of the clouds thus rising and discharging themselves, which does not happen twice in an age, there would be an enormous mass of ice there, built up by the various layers of the hail; and this I found very thick in the middle of July. And I saw the atmosphere dark overhead, and the rays of the sun striking the mountain had far more brightness than in the plains below, because less thickness of atmosphere lay between the summit of this mountain and the sun.

As a further example of the colour of the atmosphere, we may take the case of the smoke produced by old dry wood, for as it comes out of the chimneys it seems to be a pronounced blue when seen between the eye and a dark space, but as it rises higher and comes between the eye and the luminous atmosphere, it turns immediately to an ashen grey hue, and this comes to pass because it no longer has darkness beyond it, but in place of this the luminous atmosphere. But if this smoke comes from new green wood, then it will not assume a blue colour, because, as it is not transparent, and is heavily charged with moisture, it will have the effect of a dense cloud which takes definite lights and shadows as though it were a solid body.

The same is true of the atmosphere, which excessive moisture renders white, while little moisture acted upon by heat causes it to be dark and of a dark blue colour; and this is sufficient as regards the definition of the colour of the atmosphere, although one may also say that if the atmosphere had this transparent blue as its natural colour, it would follow that wherever a greater quantity of atmosphere came between the eye and the fiery element, it would appear of a deeper shade of blue, as is seen with blue glass and with sapphires, which appear darker in proportion as they are thicker. The atmosphere, under these conditions, acts in exactly the opposite way, since where a greater quantity of it comes between the eye and the sphere of fire, there it is seen much whiter, and this happens towards the horizon; and in proportion as a lesser amount of atmosphere comes between the eye and the sphere of fire, of so much the deeper blue does it appear, even when we are in the low plains. It follows therefore, from what I say, that the atmosphere acquires its

[1] MS. has reta which Dr. Richter reads in sense of 'malanno'. I have adopted Dr. Solmi's suggestion 'rarità'. (Note, Dec. 1929. Calvi reads [ra]retà.)

blueness from the particles of moisture which catch the luminous rays of the sun.

We may also observe the difference between the atoms of dust and those of smoke seen in the sun's rays as they pass through the chinks of the walls in dark rooms, that the one seems the colour of ashes, and the other — the thin smoke — seems of a most beautiful blue. We may see also in the dark shadows of mountains far from the eye that the atmosphere which is between the eye and these shadows will appear very blue, and in the portion of these mountains which is in light, it will not vary much from its first colour.

But whoever would see a final proof, should stain a board with various different colours, among which he should include a very strong black, and then over them all he should lay a thin transparent white, and he will then perceive that the lustre of the white will nowhere display a more beautiful blue than over the black, — but it must be very thin and finely ground.

Leic. 4 r.

Smoke is swift at its beginning and becomes slower at every stage of its ascent, because it becomes colder and heavier, owing to the fact that a great part of it is condensed through the parts striking against each other and being pressed together and made to adhere one to another; and water does the same for it is swift at the beginning of its movement.

Leic. 12 v.

Air even if it changes its position preserves the impression of its eddies more than water does, from the fact of it being swifter and thinner.

Leic. 30 v.

An excess of smoke acts as a veil, a small quantity of it does not render the perfection of this blue: it is by a moderate admixture of smoke therefore that the beautiful blue is created.

Experience it is that shows how the air has darkness behind it and yet appears blue.

Make smoke of dry wood in a small quantity; let the rays of the sun fall upon this smoke, and behind it place a piece of black velvet, so that it shall be in shadow. You will then see that all the smoke which comes between the eye and the darkness of the velvet will show itself of a very beautiful blue colour; and if instead of the velvet you put a white cloth, the smoke will become the colour of ashes.

How water blown in the form of spray into a dark place, through which the solar rays pass, produces this blue ray; and especially when this water has been distilled; and how the thin smoke becomes blue. This is said in order to show how the blue colour of the atmosphere is caused by the darkness that is above it; and the above-mentioned instances are offered for the benefit of anyone who cannot confirm my experience on Mon Boso.[1]

Leic. 36 r.

[1] See Leic. 4 r. in which Leonardo refers to his ascent of Mon Boso (Monte Rosa) in the month of July and the atmospheric conditions which he found prevailing.

XVII

Flight

'I have divided the *Treatise on Birds* into four books; of which the first treats of their flight by beating their wings; the second of flight without beating their wings and with the help of the wind; the third of flight in general, such as that of birds, bats, fishes, animals and insects; the last of the mechanism of this movement.'

Those feathers which are farthest away from their points of attachment will be most flexible.

The tips of the feathers of the wings therefore will always be higher than their roots, wherefore we may with reason say that the bones of the wings will always be lower when the wing is lowered than any part of the wing; and when it is raised these bones of the wing will be higher than any part of this wing. Because the heavier part will always be the guide of the movement.

I ask in what part of the under surface of the breadth of the wing does this wing press the air more than in any part of the length of the wings.

Every body that does not bend, although these are each in itself of different size and weight, will throw equal weights upon all the supports which are equidistant from their centre of gravity, this centre being in the middle of the breadth of this body.

But if the said body is flexible with varying thicknesses and weights, although the centre of gravity may be in the centre of its magnitude, this will not prevent the support that is nearest the centre of its gravity, or of other inequality of gravity, from being more charged with weight than that which is above the lighter parts.

Sul Volo 4 v.

The man in a flying machine [has] to be free from the waist upward in order to be able to balance himself as he does in a boat, so that his centre of gravity and that of his machine may oscillate and change where necessity requires through a change in the centre of its resistance.

When the bird desires to turn to the right or left side by beating its wings, it will beat lower with the wing on the side on which it wishes to turn, and thus the bird will twist its movement behind the impetus of the wing which moves most,

Sul Volo 6 [5] r.

and makes the reflex movement under the wind from the opposite side.

When the bird desires to rise by beating its wings it raises its shoulders and beats the tips of the wings towards itself, and comes to condense the air which is interposed between the points of the wings and the breast of the bird, and the pressure from this air raises up the bird.

The kite and the other birds which beat their wings only a little, go in search of the current of the wind; and when the wind is blowing at a height they may be seen at a great elevation, but if it is blowing low down then they remain low.

When there is no wind stirring in the air then the kite beats its wings more rapidly in its flight, in such a way that it rises to a height and acquires an impetus; with which impetus, dropping then very gradually, it can travel for a great distance without moving its wings.

And when it has descended it does the same over again, and so continues for many times in succession.

This method of descending without moving the wings serves it as a means of resting in the air after the fatigue of the above-mentioned beating of the wings.

All the birds which fly in spurts rise to a height by beating their wings; and during their descent they proceed to rest themselves, for while descending they do not beat their wings.

Sul Volo 6 [5] v.

OF THE FOUR REFLEX AND FALLING MOVEMENTS MADE BY BIRDS UNDER DIFFERENT CONDITIONS OF THE WIND

The slanting descent of birds made against the wind will always be made beneath the wind, and their reflex movement will be made upon the wind.

But if this falling movement is made to the east when the wind is blowing from the north then the north wing will remain under the wind and it will do the same in the reflex movement, wherefore at the end of this reflex movement the bird will find itself with its front to the north.

And if the bird descends to the south while the wind is blowing from the north it will make this descent upon the wind, and its reflex movement will be below the wind; but this is a vexed question which shall be discussed in its proper place for here it would seem that it could not make the reflex movement.

When the bird makes its reflex movement facing and upon the wind it will rise much more than its natural impetus requires, seeing that it is also helped by the wind which enters underneath it and plays the part of a wedge. But when it is at the end of its ascent it will have used up its impetus and therefore will depend upon the help of the wind, which as it strikes it on the breast would throw it over if it were not that it lowers the

right or left wing, for this will cause it to turn to the right or left dropping down in a half circle.

Sul Volo 7 [6] r.

[*Of a flying machine*]

The movement of the bird ought always to be above the clouds so that the wing may not be wetted, and in order to survey more country and to escape the danger caused by the revolutions of the winds among the mountain defiles which are always full of gusts and eddies of winds. And if moreover the bird should be overturned you will have plenty of time to turn it back again following the instructions I have given, before it falls down again to the ground.

If the point of the wing is struck by the wind and the wind enters underneath the point the bird will then find itself liable to be overturned unless it employs one of two remedies; that is either it suddenly enters with this point under the wind or lowers the opposite wing from the middle forward.

(*Figure*) *a b c d* are the four cords above for raising the wing, and they are as powerful in action as the cords below, *e f g h*, because of the bird being overturned so that they may offer as much resistance above as they do below, although a single strip of hide dressed with alum thick and large may chance to suffice: but finally however we must put it to the test.

Sul Volo 7 [6] v.

The bird I have described ought to be able by the help of the wind to rise to a great height, and this will prove to be its safety; since even if all the above-mentioned revolutions were to befall it, it would still have time to regain a condition of equilibrium; provided that its various parts have a great power of resistance, so that they can safely withstand the fury and violence of the descent, by the aid of the defences which I have mentioned; and its joints should be made of strong tanned hide, and sewn with cords of very strong raw silk. And let no one encumber himself with iron bands, for these are very soon broken at the joints or else they become worn out, and consequently it is well not to encumber one's self with them.

The cord *a* set for the purpose of extending the wing ought to be of thick dressed hide, so that if the bird should be turned upside down it may be able to subdue the fury of the wind which strikes it on the wing and seeks to close it, for this would be the cause of the destruction of the

bird. But to make it more safe you should make exactly the same system of cords outside as within, and you will then avoid all suspicion of danger.

a b c are the terminating points of the cords from the three joints of the fingers of the wings; *d* marks the position of the mover of the lever *a d* which moves the wing. Sul Volo 8 [7] r.

When the edge of the point of the wing meets the edge of the wind for a brief moment this wing sets it either below or above this edge of the wind, and the same happens with the point and sides of the tail and in like manner with the helms of the shoulders of the wings.

The descent of the bird will always be by that extremity which is nearest to its centre of gravity.

The heaviest part of the bird which descends will always be in front of the centre of its bulk.

3rd. When without the help of the wind the bird is stationary in the air without beating its wings in a position of equilibrium, this shows that its centre of gravity is identical with the centre of its bulk.

4th. The heaviest part of the bird which descends head foremost will never remain above or level with the height of its lightest part.

If the bird falls with its tail downwards by throwing its tail backwards it will regain a position of equilibrium, and if it throws it forwards it will come to turn right over.

1st. When the bird being in a state of equilibrium sends the centre of resistance of its wings behind its centre of gravity it will descend with its head below.

2nd. And this bird which is in a state of equilibrium will have the centre of resistance of its wings in front of its centre of gravity; this bird will then drop with the tail turned to the ground.[1] Sul Volo 8 [7] v.

If the wing and the tail are too far above the wind lower half the opposite wing and so get the impact of the wind there within it, and this will cause it to right itself.

If the wing and the tail should be beneath the wind raise the opposite wing and it will right itself as you desire, provided that this wing which rises slants less than the one opposite to it.

[1] The odd order of the numbered paragraphs here and elsewhere in the MSS. suggests that the numbers may have been added with the intention of amending the order when the work should take its final form.

And if the wing and the breast are above the wind it should lower the half of the opposite wing, and this will be struck by the wind and thrown back upwards, and this will cause the bird to right itself.

But if the wing and the spine are below the wind it ought then to raise the opposite wing and expand it in the wind, and the bird will immediately right itself.

And if the bird is situated with the hinder part above the wind the tail ought then to be placed beneath the wind, and thus there will be brought about an equilibrium of forces.

But if the bird should have its hinder parts below the wind (*raising its tail*[1]) it should enter with its tail above the wind and it will right itself.

Sul Volo 9 [8] r.

When the bird is above the wind, turning its bill with its trunk to the wind the bird would be liable to be overturned unless it lowered its tail and received in it a great volume of wind; and if it acts thus it is impossible for it to be overturned. This is proved by the first section of the Elements of Mechanics, which shows how things in equilibrium which are struck outside their centre of gravity send down the opposite sides which are situated on this side of the aforesaid centre. . . .

(*Example*)

And if the bird is situated with its length under the wind it is liable to be thrown upside down by the wind unless it instantly raises up its tail. . . .

How the expanse of the wing is not all used in compressing the air; and for the truth of this see how the openings between the chief feathers are much wider spaces than the actual breadth of the feathers.

You therefore who make research into winged creatures do not take into your reckoning the whole expanse of the wing, and note the different characteristics of the wings of all winged creatures.

Sul Volo 9 [8] v.

When the wind strikes the bird under its course from its centre of gravity towards this wind then the bird will turn with its spine towards the wind; and if the wind was more powerful below than above the bird would be turned upside down if it were not instantly alert to draw to

[1] Words crossed out in MS.

itself the lower and stretch out the upper wing; and by this means it rights itself and returns to the position of equilibrium.

This is proved thus: — let *a c* be the wing folded up beneath the bird, and *a b* the wing extended; I say that the forces of the wind which strike the two wings will have the same proportion as that of their extension, that is *a b* as against *a c*. It is true that *c* is wider than *b*, but it is so near the bird's centre of gravity that it offers small resistance in comparison with *b*.

But when the bird is struck under the wind, beneath one of its wings, it would be possible for the wind to overturn it if it were not that so soon as ever it is turned with its breast to the wind it extended the opposite wing towards the ground, and drew up the wing which was first struck by the wind which remains uppermost, and thus it will come to return to a position of equilibrium. This is proved by the fourth of the third according to which that object is more mastered which is opposed by a greater force; also by the fifth of the third which is that this support resists less and is situated farther away from its fixed point; also by the fourth of the third: among winds of equal force that will be of greater force which is of greater volume, and that will strike with a greater volume which finds a greater object; wherefore *m f* being longer than *m n*, *m f* will obey the wind. Sul Volo 10 [9] r.

If the bird should wish to turn itself rapidly on one of its sides and to follow its circular movement it will beat its wings twice on that side, moving the wing back like an oar and keeping the other wing steady or making only one beat with this as against two of the opposite wing.

Since the wings are swifter to press the air than the air is to escape from beneath the wings the air becomes condensed and resists the movement of the wings; and the motive power of these wings by subduing the resistance of the air raises itself in a contrary movement to the movement of the wings.

That bird will descend with the swifter movement when its descent is at a less angle.

The descent of a bird will be at a less angle when the tips of the wings and their shoulders are nearer together.

The lines of the movements made by birds as they rise are of two kinds, of which one is always spiral in the manner of a screw, and the other is rectilinear and curved.

That bird will rise up to a height which by means of a circular movement in the shape of a screw makes its reflex movement against the coming of the wind and against the flight of this wind, turning always upon its right or left side.

Thus if the north wind should be blowing, and you coming above in reflex movement, should glide against the said wind, until, in this straight process of rising, the wind was in such a condition that it might turn you over, you are then at liberty to bend with the right or left wing, and holding the inner wing low you will pursue a curving movement, with the help of the tail, curving in the direction of the lower wing, and continually descending and pivoting round the wing that is held low, until you again make the reflex movement anew above the wind, behind the course of the wind; and when you are on the point of being turned over this same lower wing will curve your line of movement, and you will return against the wind, underneath it, until you have acquired the impetus, and then raise yourself above the wind, facing its approach, and by means of the already acquired impetus, you will make the reflex movement greater than the falling movement.

A bird as it rises always sets its wings above the wind and without beating them, and it always moves in a circular movement.

And if you wish to go to the west without beating your wings, when the north wind is blowing, make the falling movement straight and beneath the wind to the west, and the reflex movement above the wind to the north.

Sul Volo (F.M.) 11 [10] r.

A bird makes the same use of wings and tail in the air as a swimmer does of his arms and legs in the water.

If a man is swimming with his arms equally towards the east, and his body exactly faces the east, the swimmer's movement will be towards the east. But if the northern arm is making a longer stroke than the southern arm then the movement of his body will be to the north-east. And if the right arm is making a longer movement than the left the man's movement will be to the south-east.

The impetus of one of the wings extended edgewise towards the tail will occasion the bird a sudden circling movement following on the impetus of the above-mentioned wing.

When the bird raises itself in circles to a height above the wind, without beating its wings, by the force of the wind, it will be transported

by this wind out of the region where it desires to return, still without beating its wings; then it turns so that it faces the approach of the wind, entering slantwise underneath this wind, and comes to descend slightly until it finds itself above the spot where it desires to return.

The edge *a* of the helm of the wing or the thumb (dito grosso) of the hand of the bird *b a* is that which sets the shoulder of the wing immediately below or above the wind. And if this shoulder did not have the power of cutting with a keen and strong edge, the wing would not be able suddenly to enter below or above the wind when it happened to be necessary for the bird, seeing that if this shoulder were round, and the wind *f e* were to strike the wing below and it should immediately befall the wing to be . . .

Sul Volo (F.M.) 11 [10] v.

. . . struck from above, the power of the wind which strikes it from above is not at its full strength, seeing that the wedge of the wind which is separated from the middle of the shoulder downwards raises the wing up almost with the same power as that exerted by the wind above to send the wing downwards.

But if the wind strikes the bird on the right or left wing, it is necessary for it to enter below or above this wind, with the point of the wing struck by this wind, and this change occupies as much space as the thickness of the points of these wings. As this change is beneath the wind the bird turns with its bill to the wind, and if it is above the wind the bird will turn with its tail as it pleases; and here arises the danger of the bird being turned upside down, if nature had not provided for this by placing the weight of the body of this bird lower than the position of the extension of the wings, as will be shown here.

Sul Volo 10 [9] v.

When the bird flies by beating its wings it does not extend its wings wholly, because the points of the wings would be too far removed from the lever and cords which move them.

If as the bird descends it moves its wings back as though they were oars the bird will make swift movement; and this comes about because the wings are striking in the air which is continually flowing in the wake of the bird to fill up the void from whence it has departed.

Sul Volo 12 [11] r.

TO ESCAPE THE DANGER OF DESTRUCTION

The destruction of these machines may come about in two ways, the first of which is when the machine breaks, the second is when it turns edgewise or almost on its edge because it ought always to descend with a long slant and almost in a level line.

As regards the preventing of the machine from being broken one may guard against this by making it as strong as possible in whatever line it may turn, that is either edgewise falling with head or tail in front, or with the point of the right or left wing, or along lines that bisect or are the quarterings of these lines as the sketch shows [*figure*]. against this by turning almost edgewise one ought at the outset to guard

As regards constructing the machine in such a way that in descending whatever may be the direction that it takes it finds the remedy prepared; and this you will do by causing its centre of gravity to be above that of the weight which it carries, always in a vertical line, and the one always at a sufficient distance from the other, that is that if the machine is thirty braccia in width the centres are four braccia apart, and as has been said one is beneath the other, and the heavier is below because as it descends the heavier part always constitutes itself in part the guide of the movement. In addition to this if the bird wishes to fall with its head downwards with a fraction of the slant that would cause it to turn over this will not be able to happen, because the lighter part would be beneath the heavier and the light would be descending before the heavy, which is impossible in a descent of any length, as is proved in the fourth of the Elements of Mechanics.

And if the bird should fall head downwards with the body partly slanting towards the ground the underneath sides of the wings ought to turn flat against the earth, and the tail to rise towards the back, and the head or the underpart of the jaw is also turned towards the ground, and from this there will immediately originate in this bird its reflex movement which will cast it up again towards the sky; for which reason the bird at the close of its reflex movement will come to fall back unless it should while rising lower one of its wings slightly, which would curve such movement and cause it to turn into a half circle; then this bird will find itself at the close of this movement with its bill turned to the spot at which this reflex movement started. And if this is done against the course of the wind the end of the reflex movement will be much higher than was the commencement of the falling movement. And this is the

way in which the bird rises up to a height without beating its wings and circling. And the remainder of the circle of which I have spoken is completed by the help of the wind, by a falling movement, with one of the wings always kept low and similarly one side of the tail. And it subsequently makes a reflex movement towards the direction of the wind and is left at the end with its bill turned in the direction of the wind, and then makes again the falling and reflex movements against the wind always going in circles.

When the bird wishes suddenly to turn on one of its sides it pushes out swiftly towards its tail, the point of the wing on that side, and since *every movement tends to maintain itself*, or rather *every body that is moved continues to move so long as the impression of the force of its mover is retained in it*, therefore the movement of this wing with violence, in the direction of the tail, keeping still at its termination a portion of the said impression, not being able of itself to follow the movement which has already been commenced, will come to move the whole bird with it until the impetus of the moved air has been consumed.

When the tail is thrust forward with its face and the wind strikes upon it it makes the bird move suddenly in an opposite direction.

Sul Volo 13 [12] r. and v.

[*With drawing of bird with wings outstretched*]

Here the big fingers of the wings are those which keep the bird motionless in the air against the movement of the wind; that is the wind moves, and it maintains itself upon it without beating its wings, and the bird does not change its position.

The reason is that the bird arranges its wings so as to slant so much that the wind which strikes it below does not form itself into a wedge of such a kind as tends to raise it, raising it however just so much as its weight wishes to lower it, that is to say if the bird's impulse to fall be expressed by two units of power the wind's impulse to rise will be expressed by two units also, and because things which are equal cannot overcome one another the bird remains in its position without either rising or falling. It remains for us to speak of the motion which does not impel it either forward or backward; and that is if the wind should wish to accompany it or drive it out of its position with a power expressed by four units and the bird with the same power is slanting at the same angle against the wind. Here also as the powers are equal the bird will not move forward nor will it be driven back when the wind is equal. But

inasmuch as the movements and powers of the winds are variable the angle of the wings ought not to change, because if the wind grows and it should alter the angle in order not to be driven upward by this wind. . . .

In the aforesaid instances the wind does not enter like a wedge underneath the slanting wings, but only meets the wing along the edge which wishes to descend against the wind; and there strikes it on the edge of the shoulder which serves as a shield for all the rest of the wing; and there would be here no protection against the descent of the wing if it were not for the big finger *a* which then comes to the front and receives the whole force of the wind full upon it, or less than full according to the greater or less power of the wind. Sul Volo 14 [13] r.

[*With drawing of wing*]

The big finger *n* of the hand *m n* is that which when the hand is lowered comes to lower itself more than the hand, in such a way as to close and prevent the exit of the stream of air compressed by the lowering of the hand, in such a way that in this place the air becomes condensed and offers resistance to the oarage of the wing. And for this reason nature has formed in this big finger a bone of such great strength, to which are united very strong sinews with the feathers short and of greater strength than the feathers which are on birds' wings, because the bird leans upon it, upon the air which is already compressed, with all the power of the wing and of its strength, because it is this by means of which the bird moves forward.

And this finger here performs for the wings the function which its claws do for a cat when it climbs up trees.

But when the wing regains fresh force with its return upward and forward, the big finger of the wing then puts itself in a straight line with the other fingers, and thus with its sharp edge it strikes the air and performs the office of a helm or rudder, which strikes the air continually in some movement high or low when the bird wishes to rise.

The second helm or rudder is placed on the opposite side beyond the bird's centre of gravity, and this is its tail, which if it is struck by the wind below, through being beyond the aforesaid centre will come to lower the bird in its front part.

But if the tail is struck above, the bird is raised in its front part. And if the tail is somewhat twisted, and shows its front slanting under the

right wing, the front part of the bird will be turned towards the right side. And if the slant of the lower side of the tail is turned to the left wing, it will turn with its front part to the left side; and in each of the two conditions the bird will descend. But if the tail in a slanting position is struck by the wind in its upper part the bird will turn revolving slowly on that side on which the upper surface of the tail shows its slant. Sul Volo 14 [13] v.

The axis of the shoulder of birds is that which is turned by the muscles of the breast and back; and it is here that the discretion of lowering or raising the tail originates according to the will or necessity of the animal that moves.

I conclude that the rising of birds without beating their wings is not produced by anything other than their circular movement amid the movement of the wind, which movement when it ceases to have the support of the wind continues to descend as far as the place at which the reflex movement starts, after which, and having thus revolving described a semicircle it finds itself again with its face turned to the wind, and follows the reflex movement, above the wind, continually revolving until with the help of the wind it makes its highest ascent between its lowest descent and the arrival of the wind, and remains with its left wing to the wind; and from this maximum elevation circling anew it drops again to the last falling movement, remaining with its right wing to the wind.

The equal power of resistance of a bird's wings is always due to the fact of their being equally remote in their extremities from the bird's centre of gravity.

But when one of the extremities of the wings is nearer the bird's centre of gravity than the other the bird will then descend on the side on which the extremity of the wing is nearer to the centre of gravity. Sul Volo 15 [14] r.

The hand of the wing is the part that causes the impetus; and the elbow is then held edgewise in order not to check the movement which creates the impetus; and when this impetus is afterwards created the elbow is lowered and set slantwise and in slanting it makes the air upon which it rests almost into the form of a wedge, upon which the wing

comes to raise itself, and if it did not do thus the movement of the bird during the time that the wing returns forward would cause the bird to fall as the impetus gradually becomes consumed; but it is not able to fall because as the impetus fails so in proportion does the pressure exerted by the elbow resist the descent and again raise the bird up.

The elbows of the creature are not lowered quite at the commencement, because in the chief flight of the impetus the bird will bound upwards, but they are lowered by as much as may be necessary to check the descent, according to the desire and discretion of the bird.

When the bird wishes to soar upwards suddenly it immediately lowers its elbows, after it has produced the impetus.

But if it wishes to descend it keeps its elbows rigid and raised up after the creation of the impetus.

Sul Volo 15 [14] v.

Remember that your bird should have no other model than the bat, because its membranes serve as an armour or rather as a means of binding together the pieces of its armour, that is the framework of the wings.

And if you take as your pattern the wings of feathered birds, these are more powerful in structure of bone and sinew because they are penetrable, that is to say the feathers are separated from one another and the air passes through them. But the bat is aided by its membrane, which binds the whole together and is not penetrated by the air.

OF THE METHOD OF BALANCING ONESELF

It will always be the heaviest part of bodies which constitutes itself the guide of their movement.

The bird which has to raise itself without beating its wings sets itself so that it slants against the wind, presenting its wings to it with the elbows in front, with its centre of gravity more towards the wind than the centre of the wings. Whence it comes about that if the power which impels the bird when slanting to descend is represented by two and the force with which the wind strikes it by three the movement obeys the three and not the two.

Sul Volo 16 [15] r.

[*With drawing of pulley with bird suspended with wings outstretched*]

This is made in order to find the bird's centre of gravity, and without this instrument this machine would have little value.

When the bird drops down its centre of gravity is outside the centre of its resistance.

And if the bird wishes to raise itself its centre of gravity remains behind the centre of its resistance.

The bird can stay poised in the air without keeping its wings in a position of equality because owing to its not having the centre of gravity in the middle of its axis as balances have, it is not necessarily obliged to keep its wings at an equal height like the said balances. But if these wings are outside this position of equality the bird will descend by the line of the slant of the wings. And if the slant is complex, that is double, as if we say that the slant of the wings points to the south, and the slant of the head and tail points to the east, then the bird will descend slanting towards the south-east. And if the slant of the bird is double the slant of its wings the bird will descend by a line midway between the south-east and the east, and the slant of its movement will be between the two positions that have been mentioned.

Sul Volo 16 [15] v.

AN ARGUMENT TO DISPOSE OF THE OBJECTIONS TO THE ATTEMPT

You will perhaps say that the sinews and muscles of a bird are incomparably more powerful than those of man, because all the girth of so many muscles and of the fleshy parts of the breast goes to aid and increase the movement of the wings, while the bone in the breast is all in one piece and consequently affords the bird very great power, the wings also being all covered with a network of thick sinews and other very strong ligaments of gristle, and the skin being very thick with various muscles.

But the reply to this is that such great strength gives it a reserve of power beyond what it ordinarily uses to support itself on its wings, since it is necessary for it whenever it may so desire either to double or treble its rate of speed in order to escape from its pursuer or to follow its prey. Consequently in such a case it becomes necessary for it to put forth double or treble the amount of effort, and in addition to this to carry through the air in its talons a weight corresponding to its own weight. So one sees a falcon carrying a duck and an eagle carrying a hare; which circumstance shows clearly enough where the excess of strength is spent; for they need but little force in order to sustain themselves, and to balance themselves on their wings, and flap them in the pathway of the

wind and so direct the course of their journeyings; and a slight movement of the wings is sufficient for this, and the movement will be slower in proportion as the bird is greater in size.

Man is also possessed of a greater amount of strength in his legs than is required by his weight. And in order to show the truth of this, place a man to stand upon the sea-shore, and observe how far the marks of his feet sink in; and then set another man on his back, and you will see how much deeper the marks of his feet will be. Then take away the man from his back, and set him to jump straight up as high as he can; you will then find that the marks of his feet make a deeper impression where he has jumped than where he has had the other man on his back. This affords us a double proof that man is possessed of more than twice the amount of strength that is required to enable him to support himself. [*With drawing*] Leather bags with which a man falling from a height of six braccia will not do himself any harm, whether he falls into water or on land; and these leather bags tied after the fashion of the beads of a rosary are wrapped round by others. Sul Volo 17 [16] r.

If you should fall with the double chain of leather bags which you have tied underneath you so manage that these are what first strike the ground.

[*With drawing of part of mechanism of flying machine*]

Since the wings have to row downwards and backwards, in order to keep the machine up and so that it may progress forward, it moves by the lever *c d* with a slanting track, guided by the strap *a b*.

I might so make it that the foot which presses the stirrup *g* was that which in addition to its ordinary function pulled down the lever *f*. But this would not serve our purpose, because it is necessary that the lever *f* should first rise or descend before the stirrup *g* moves from its place, in order that the wing — as it throws itself forward and raises itself up at the time at which the already acquired impetus of itself drives the bird forward without it beating its wings — can present itself edgewise to the air, because if it did not do this the surface of the wings would clash upon the air, would hinder its movement, and would not allow the impetus to carry the bird forward. Sul Volo 17 [16] v.

If the bird drops to the east with its right wing extended above the

south wind then undoubtedly it will be turned over unless it suddenly turns its bill to the north; and then the wind will strike the palms of its hands beyond the centre of its gravity and will raise up again the part of the bird which is in front.

When the bird has great breadth of wings and a small tail and wishes to raise itself up it will raise its wings vigorously and will in turning receive the wind under its wings; this wind forming itself into a wedge will drive it up to a height with swiftness as is the case with the cortone, a bird of prey which I saw going to Fiesole above the place of the Barbiga in 5 (the year 1505) on the fourteenth day of March.

Movements of the tail: how sometimes it is flat and the bird as it moves has it in a level position; sometimes it has the extremities equally low and it is then that the bird rises; sometimes it has the extremities equally high and this occurs when it descends. But when the tail is low and the left side is lower than the right the bird will then rise with a circling movement towards the right side; this may be proved but not here. And if when the tail is low the right extremity is lower than the left the bird will turn towards the left side. And if when the tail is high the left side of its extremities is higher than the right the bird will then turn with its head towards the right side; but if when the tail is high the right side of its extremities is higher than the left then the bird will circle towards the left side.

Sul Volo (F.M.) 18 [17] v.

[*With drawings of birds' wings*]

Always in raising the hand the elbow is lowered and presses the air, and as this hand is lowered the elbow rises and remains edgewise, in order not to check the movement by means of the air which would strike into it.

The lowering of the tail at the time that the bird sends its wings forward again edgewise a little above the wind, guided by the impetus already acquired, is the reason why the wind strikes under this elbow and forms itself into a wedge, upon which the bird proceeds to rise with the aforesaid impetus without beating its wings.

And if the bird be three pounds and the breast a third the width of the wings the wings will only bear two thirds of the bird's weight.

The hand feels great fatigue towards the thumb or rather the helm of the wing because this is the part that strikes the air.

The palm of the hand goes from *a* to *b* always between almost equal

angles, dropping and pressing the air, and at *b* it turns immediately edgewise and goes backwards, rising by the line *c d*, and having arrived at *d* it turns suddenly opposite and goes dropping by the line *a b*, and as it turns it always turns round the centre of its breadth.

The turning of the hand backwards edgewise will be done with great rapidity, and the pressing of it backwards open will be done with such rapidity as the final urge of the motive power requires.

The course of the point of the fingers is not the same in going as in coming back but it follows a higher line in returning; and beneath this is the figure made by the higher and lower line, and it is oval with a long and regular curve.

Sul Volo 18 r.

The great bird will take its first flight upon the back of the great swan, filling the whole world with amazement and filling all records with its fame; and it will bring eternal glory to the nest where it was born.

Sul Volo, cover, 2 r.

1505 on the evening of Tuesday the fourteenth day of April Lorenzo came to live with me: he said that he was seventeen years of age.

And on the fifteenth day of this April I had twenty-five gold florins from the treasurer of Santa Maria Nuova.

From the mountain which takes its name from the great bird, the famous bird will take its flight, which will fill the world with its great renown.[1]

Sul Volo 18 v.

If the bird wishes to make headway against the wind it beats its wings and moves them as oars backwards.

C.A. 37 r. b

Unless the bird beats its wings downwards with more rapidity than

[1] This passage should be regarded as a key to the one before it. In the phrase 'sopra del dosso del suo magnio cecero', 'upon the back of the great swan', Leonardo was apparently referring to Monte Ceccri, the mountain above Fiesole immediately to the south. It was from the summit or from a ridge of this mountain that he intended to make a trial of his flying machine. The locality is also referred to in another page of the same manuscript where he speaks of 'the cortone a bird of prey which I saw going to Fiesole above the place of the Barbiga in the year 1505 on the fourteenth day of March' (Sul Volo, Fogli Mancanti 18 [17] v.). This points to the probability that 1505 was the year in which the trial took place. It may have been this trial of which Cardan chronicled the ill success.

there would be in its natural descent with its wings extended in the same position, its movement will be downwards. But if the movement of the wings is swifter than the aforesaid natural descent then this movement will be upwards, with so much greater velocity in proportion as the downward stroke of the wings is more rapid.

The bird descends on that side on which the extremity of the wing is nearer to the centre of its gravity.

You will make an anatomy of the wings of a bird together with the muscles of the breast which are the movers of these wings.

And you will do the same for a man, in order to show the possibility that there is in man who desires to sustain himself amid the air by the beating of wings. C.A. 45 r. a

[*With figures*]

The bird which descends above or below the wind keeps its wings closed in order not to be held up or checked by the air; it keeps them well above its body, so that it may not be turned upside down by the impetus.

When the bird keeps the shoulders of its wings closed and their points wide it makes the air thicker than the other air where it does not pass; and it does this in order to check its movement and not deviate from the line of this movement.

But when the bird opens the shoulders more than the points of its wings it wishes to delay the movement more forcibly.

When the points and the shoulders of the wings are equally near to each other the bird wishes to descend without being checked by the air.

When the bird uses its wings as oars, or beats the wings backwards in their descent, it is a clear sign that it increases the speed of its descent.

Here by means of the attitudes of the birds one sees the results of the effects and both of these joined together show the intention of the bird.

The wing extended on one side and drawn up on the other show the bird dropping with a circular movement round the wing that is drawn up.

Wings drawn up equally show that the bird wishes to descend in a straight line.

The bird above the wind at the end of the reflex movement will never keep its wings open equally, because it would be turned upside down

by the wind. But it draws that wing in to itself round which it desires to make the revolving movement, and descends behind it and moves in a circle behind it, when it wishes to rise or descend.

The opponent says that he has seen the proofs of how the bird standing with its wings entirely open cannot descend perpendicularly to its own hurt or the damage of any part, and that he admits the proofs that it cannot fall backwards edgewise because he cannot deny the proofs assigned, and also it cannot fall with its head below it; but that he doubts whether if it should find itself with the line of the breadth of the wings perpendicular to the ground it would not descend edgewise along this line. Here the reply is that in this case the heaviest part of the bodies would not be a guide of the movement, and such movement would be contrary to the fourth of this, which was proved to be impossible.

C.A. 66 r. a

The rudders of the wings of birds are the parts which immediately place the bird above or below the coming of the wind, and with their tiny movement cleave the air in whatever line along the opening of which the bird can then penetrate with ease.

The bird will never descend backwards because its centre of gravity is nearer to the head than towards the tail.

The descent of the bird in all or part of its movement will always be along that line in which its centre of gravity is nearest to the extremities of the width of the bird.

I have said the descent will be entirely towards that part which is nearest to the centre of gravity when one part only is near to this centre of gravity, and the extremities of the other opposite parts remain equidistant from this centre; as when the bird presses its head close in to its body and the wings remain equally distant from the centre tail straight and wide, the bird will then descend with its head in front, and the body in its central line will direct itself by this movement.

But when in such movement one of the wings narrows itself towards the said centre the line of the bird's descent will be between the gathered-in wing and the head of the bird.

And if during the movement of the wings, when opened equally, the tail should bend towards one of the wings, the movement will then continue between the head of the bird and the opposite wing.

And if the head only is bent down towards one of the wings open

equally, the slanting descent will then proceed between the head and the wing which the head is near.

Swimming upon water teaches men how birds do upon the air.

C.A. 66 r. b

HOW THE BIRD STOPS ON THE WING ABOVE THE WIND AND DOES NOT MOVE FROM ITS POSITION

If the wind which drives the bird forward is of the same power as the bird, that stays above the wind and desires to drop towards this wind, the bird will then be motionless; and the movement which it was on the point of making will be made by the wind from the opposite side.

And if the wind is more powerful and the bird moves its wings backwards as oars, the bird will be motionless.

And if the wind comes from above and in front, and the bird resists it below and behind, then according to the conditions of the places whence it may fall the bird remains motionless.

But when the wind comes in front and below it will be more powerful than the weight of the bird; it will then be necessary for the wings to contract and occupy less of the atmosphere, and consequently they will be smitten by a lesser quantity of wind, and for the strokes which it takes to have rather a backward direction, and then the bird will remain motionless.

C.A. 71 r. b

The simple power of the man will never work the wing of the crow with such swiftness as the crow did when it was attacked.

And the proof of this will be shown in the uproar they make, for that of the man will never produce so great a noise as the wing of the bird made when it was attacked.

WHY THE BIRD SUSTAINS ITSELF UPON THE AIR

The air which is struck with most swiftness by the movable thing is compressed to the greatest degree in itself.

This is proved by the fact that the less thick flexible body will never support the thicker upon itself, as for example one sees the anvil floating upon melted bronze, and gold and silver when liquefied staying beneath a fusion of lead; and for this reason, as the atmosphere is a body capable of being itself compressed when it is struck by something which is

moving at a greater rate of speed than that of its flight, it is compressed into itself and becomes like a cloud within the rest of the air, that is it is of the same density.

But when the bird finds itself within the wind, it can sustain itself above it without beating its wings, because the function which the wing performs against the air when the air is motionless is the same as that of the air moved against the wings when these are without motion.

C.A. 77 r. b

WHY THE BIRD FALLS IN A PARTICULAR LINE

On whatever side the weight of the bird is as it drops from a position of equality, on that side its descent will be.

And at whatever angle the bird sets itself, in the same angle its descent will be.

And if a part is bent forward and the wings spread out at an equal slant, the movement of the bird will be in the centre of the two inclined parts.

And this movement will slope more towards the part which bends more.

[*Drawing*]

That circle will be of less size in which the bird sets itself on a less slanting line.

The slant of the wings always tends to be equal to the slant of the body of the bird.

[*Drawing a b*]

If the wings are held slanting and the bust in a position of equality, without doubt the bird will descend along the line of the slant of the wings; but this slant will be varied to the right or left as is in the movement *a b*.

C.A. 77 v. b

HOW MANY ARE THE WAYS IN WHICH A BIRD TURNS ITS STRAIGHT MOVEMENT INTO A CURVING MOVEMENT?

The bird that wishes to turn its straight course into a curved one without raising or lowering its height, moves the wing on the convex side of its curving movement more frequently than it does that on the concave side of this movement.

The wing of the bird as it beats its wings has the shoulder raised more in front than behind; and this it does in order to acquire movement,

because if the wings were to move equally up and down the bird would not move from its first position.

The bird bends its straight course towards that side on which the wing is most lowered. And it is as though this wing were more smitten by the wind than the other.

OF THE BIRD AS IT FLIES WITH BOUNDS (BALZI)

The bird which flies with a bound acquires impetus in its descent, because in the course of this by closing its wings it acquires weight, and consequently velocity; it follows therefore that the reflex movement is more powerful, and adding to this the fact of it beating its wings, it creates double the power which is produced by the simple reflex movement, and by the fact of this duplication the reflex movement becomes longer than it would have been without the addition made by the beating of its wings. And this is the real cause why the reflex movement is equal to its falling movement and why at the end of the flight there is equality in the extent of its descent and of its ascent.

When the bird descends with a great slant without beating its wings all the extremities of the wings and tail bend upwards, and this movement is slow, for the bird is not only supported by the air beneath it but by the lateral air towards which the convex surface of the bent feathers spreads itself at equal angles.

When the bird rises from the ground to a height and leaps and closes its open wings with impetus, and makes a wave of the air which is compressed and strikes upwards at its breast from below, the impetus of this tending to continue, the movement drives the bird to a height, and it flaps its wings many times quite regularly in the course of this movement until it has risen up sufficiently.

The bird which rises with a circular movement stays in a slanting position with the breadth of its wings, and the circle in which it revolves will be so much greater in proportion as its position is more slanting; and this circle will be so much smaller as its position is less slanting.

The bird which makes a greater movement with one wing than the other will describe a circular movement, and the movement will also be circular when the wing is beaten on one side and held motionless on the other; and the circle will be so much greater or less according as this wing is moved more slowly or more rapidly.

Movement of the bird driven by the wind:

The bird which is driven by the wind, when it raises itself without beating its wings lengthens the turning process more in the falling movement than in the reflex movement; but in the reflex movement it rises and in the falling movement it lowers itself.

The bird in descending against the wind lowers its feet as the wind strikes them, and this it does in order not to disarrange the tail from the direction of the whole body when it wishes to lower itself. C.A. 97 v. a

The bird which makes the shortest revolving movement prepares the extreme extension of its wings with less slant, and for this reason the circle of its revolving movement is so much more curved as the revolving movement is shorter.

The bird can never move backward, because the points of the wings when extended are never farther in front than the centre of gravity which the length of the bird has of itself, and this must of necessity be the case; whereas if it should move backwards its feathers would turn right over in front and restrain the movement with their resistance; and this the bird shows us, for when it is resting it always turns its beak to the wind.

If the left horn of the tail is as far above the centre line of movement, and above the centre line of the weight which the bird has in the line of its movement, as the right horn of this tail is below the said centres, the movement of the bird will of necessity be straight, because the left horn of the tail is as powerful to bend the straight movement of the bird to the right when it is above the bird as the right horn of this tail is to bend the bird to the left when it is below the bird.

The bird will always descend in the direction in which it weighs most.

The bird weighs most in the direction in which its breadth is least. [*Diagram*] Therefore it will descend by the line *a b* and not by the line *b a*.

I have seen the sparrow and the lark fly upward in a straight line when they were in a level position. And this happens because the wing raised with swift movement remains filled with holes, and only rises with the impetus it has acquired, and this is renewed in the lowering of the wings, for the wing then reunites and presses one feather in beneath another, as is said in the eighth of this.

The bird which descends with the wind that strikes it below increases this descent by raising its tail, exposing the under part of it to the percussion of the wind.

The bird whenever it rests upon any spot always takes up its position with its beak against the approach of the wind.

It is always the under side of the branches of any plant that show themselves to the wind which strikes it, and one leans against another.

C.A. 160 r. b

Unless the movement of the wing which presses the air is swifter than the flight of the air when pressed, the air will not become condensed beneath the wing, and in consequence the bird will not support itself above the air.

That part of the air which is nearest to the wing will most resemble in its movement the movement of the wing which presses on it; and that part will be more stable which is farther removed from the said wing.

That part of the air which is nearest to the wing which presses on it, will have the greatest density.

The air has greater density when it is nearer to water, and [greater rarity] when it is nearer to the cold region, and midway between these it is purer.

The air of the cold region offers no resistance to the movement of the birds unless they have already passed through a considerable space of the air beneath them.

The extremities of the wings of birds are of necessity flexible.

The properties of the air are such that it may become condensed or rarefied.

C.A. 161 r. a

No impetus created by any movement whatever can be immediately consumed, but if it finds an object which has a great resistance it consumes itself in a reflex movement.

The impetus acquired by the beating of the wings in the slanting descent of birds is the reason for these birds descending for a long space without beating their wings and for the said slant.

Define what impetus is and what slanting movement consists in, and which has the greater or less slant, and how the reflex movement of birds becomes more or less slanting according to the greater or less opening of the tail and wings.

The impetus acquired will be more permanent when the movement of the descent slants less.

Impetus is a power of the mover applied in a movable thing which causes the movable thing to move after it is separated from its mover.

[There will never be impetus unless the resistance of the movable thing is completely subdued by its mover.] And especially when the dense friction of the bodies moved resists the movable thing.

This may be seen in the case of a beam drawn by oxen which only moves so long as the oxen are in movement, and when the cause has ceased the effect fails, that is that the movement of the beam ends together with the movement of the oxen.

When the friction of the movable thing over the place where it is moved is of slight density, the power of the mover will be united for so great a space with the movable thing, since this is separated from the mover in proportion as the friction is of less density. So one sees a barge drawn through the water for a certain distance of its own accord after it has been separated from the power of its mover; and the bird, after it has beaten its wings, moves upon the compressed air without any further beating of its wings, carried for a long distance by its impetus.

Movable things and movers are of three kinds, of which one moves through as much space as the movement made by its mover, and this is only slightly dominated by the power of the mover; another moves through a much less space than that traversed by the mover, and this in itself is of greater resistance than the power of its mover, not taking into account the space that intervenes between the mover and the movable thing; the third moves in the same time through a considerably greater space than that over which its mover is moved; and this movable thing in itself not taking into account the intervening space has much less power of resistance than its mover.

There are other powers of mover and movable things, in which the movable thing follows or is followed by its movement over such space and direction as has that of its mover, and after the mover remains without movement the movable thing exerts the power of the mover, and by means of this it moves through a long tract of space, as the arrow does when shot from the cord of the bow, which moves for a long time by itself, after the cord of the bow has separated itself from it.

C.A. 161 v. a

The bird may stay in the air without change of position, even if the power of the wind is greater than the power of the weight of this bird; and it does this with a slight swift movement of the wings using them as oars behind the flight of the wind with greater speed than that of this wind, and so it is in a position of equilibrium.

The bird may stay in the air without change of wings or of position, even if the power of the movement of the air is more powerful than the weight of the bird. And this contrast is due to its slant and it is in a slanting line.

When there is the same span of wing the bird which is in a more sloping line will be the heavier in the air. C.A. 180 r. a

The bird which beats its wings with equal movement without beating its tail will have a straight movement; but if one of the wings drop more than the other the straight movement will be changed to a curve and it will circle downwards round a spot below to which the lower wing is pointing. C.A. 184 v. c

[*With diagrams*]

Sudden changes of the wings and tail of birds make sudden changes in the lines of their movements. For suppose the bird is moving in an eastward direction and suddenly turns towards the west; this sudden turn is effected by extending one of its wings on the side on which it wishes to turn, and turning it so that it faces the percussion of the air in the line in which it is moving, drawing the opposite wing to itself and bending the tail in such a way that that extended wing, that is as in the bird *a d f*, is flying towards you, and as it flies it immediately turns itself backward by its right side in *f*, and then extends this wing *d f* more than usual, displaying it more in front to the wind; and the opposite wing *a c* will be bent as in *c b*, and the tail *c d* will turn as in *e d*; then the fury of the impetus is struck by the air, and works more in that part of the bird which is more remote from its centre of gravity, and less in that nearer to it.

When the bird rises in a circle without beating its wings it keeps its centre of gravity much lower than the tips of its wings, and receives the wind underneath it from whatever side it may come, after the manner of a wedge, that is either under its tail or its breast or each of its wings.

If the water *a b* strikes the tail of the fish which is in the axis above

the centre of its accidental gravity there is no doubt that this fish will bend round this centre; but its tail will bend more in the current of the water than its trunk will, for this being firmer offers more resistance in its contrary movement.

The impetus which was circular in its commencement may follow out in itself the same circular movement upon its axis as that of the millstone or the revolving wheel, and may follow it circular or straight, as the wheel of the cart revolving naturally outside of its axis or as the reflex movement made in a slanting line by the spherical bodies. Similarly the flight of birds, even though the beginning of the bird's impulse may be caused by direct movement, may continue in circular movement for as great a distance as this impetus endures.

The level movement of birds when they fly may swiftly be changed either to a slanting or vertical movement towards the sky or towards the earth. The movement towards the sky occurs when the helms of the wings and also the tail are turned towards the earth.

When a bird is descending it keeps a straighter course and has less risk of being overturned if it has its wings bent beneath it than if it keeps them straight.

When a bird's centre of gravity is below its wings it has so much the less risk of being turned upside down, as is seen above.

Make a small one to go over the water, and try it in the wind without much depth of water over some part of the Arno, with the wind natural, and then as you please, and turn the sail and the helm.

See to-morrow to all these matters and the copies, and then efface the originals and leave them at Florence, so that if you lose those that you take with you the invention will not be lost . . .

There is as much power of movement in the water or the air against an object as there is in this object against the air or the water.

The centre of gravity of the fish lying level in the water or of the bird lying level in the air is situated midway between the extremities which offer equal resistance.

Write of swimming under water and you will have the flight of the bird through the air. There is a suitable place there where the mills discharge into the Arno, by the falls of Ponte Rubaconte.

There are two different ways in which a bird can turn in any direction while continually beating its wings. The first of these is when at the same time it moves one wing more rapidly downwards than the

other with an equal degree of force, the movement approximating towards the tail; the second is when in the same space of time the movement of one wing is longer than that of the other. Also in striking with the wings downwards slantwise, if they become bent or moved one lower down and the other farther back, the part which drives the wing lower down will be higher in the first case, and the opposite part of the wings which has the longer movement backward will go farther forward through this first; consequently for this reason the movement of the bird will form a curve round that part of it which is highest.

These then are all the movements made by the bird without beating its wings, and they are each and all subject to a single rule, for all these movements rise upon the wind, for they expose themselves to it slantwise receiving it under their wings after the manner of a wedge.

C.A. 214 r. d

[*Figure*]

The centre of gravity of this bird forms the axis of its equilibrium.

When this bird raises itself in circles by a single wind without beating its wings it keeps the impetus of the wind under its wings so that they raise it as though it was a wedge.

When the wind enters under the left wing it passes above the right wing, and this wind would throw the bird over, if it were not that the tail is suddenly twisted so that the wind passes over it and makes a wedge opposite to it, and so drives it in and turns it.

When it has turned so much that the wind strikes it in the beak the tail will only work in a straight line; but it bends upwards so that the wind strikes it above and at the same time the breast and wings are struck from below, but since the force of impact on the left wing is greater because it is more bent the bird has to wheel round and turn its right wing to face the wind.

When the tip of the right wing enters into the line of the wind, nothing is so useful in order to make the wind strike at more equal angles as is the bending of the head and also the neck against the approach of this wind.

When the tail enters into the line of the wind then this tail is struck beneath by the movement of the wind, and the head is struck above, and each of the wings are struck beneath. But the right wing in twisting is more exposed to and affected by the stroke of the wind than is the

left, and therefore it travels more with the right than with the left, and therefore its movement becomes a curve and continually rises being pushed up from below by the wind.

The movement of the wing against the air is as great as that of the air against the wing.

The wing which is most extended strikes against a greater quantity of air, and as a consequence descends less than the wing which is more folded up; therefore the descent of this flying thing will be made along the line of that wing which is more folded up.

That wing is more delayed which is struck by the air at more equal angles or by a greater quantity of air.

Therefore when the bird descends in a slanting direction and perceives itself to be dropping with its left wing it will extend this wing more than the other, that is it will bend it more in face of the air where it strikes. C.A. 214 v. a

[*Drawing*]

A bird raises itself more swiftly when the circles in which it rises are smaller.

What is here set forth occurs because the bird as it rises without beating its wings by the help of the wind receives the wind underneath it in the manner of a wedge, and this wedge has its greater angle upon the side that slopes less, and therefore it raises the object above it more and more.

The bird never moves upward unless the wind enters underneath it and forms itself into a wedge, driving it for a certain distance along the line of its course.

[*Diagram*]

See to-morrow morning whether the bird as it turns coming against the wind *n* remains in the line *a b* keeping its head at *b* or whether it remains in the line *c d*.

Here there rises a doubt, namely, whether the wedge does not raise the object which is situated above itself in a perpendicular line, if this object is not supported in such a way that it has no power to fly before the blow together with the wedge, as the bird will be able to rise above the wind which serves it as a wedge, so that this wind will not carry it with it; it will be so much the more difficult therefore for this bird to rise to a height against the wind if it has not already mounted after the manner in which water falls in an empty screw. C.A. 220 r. a

HOW A BIRD LOWERS ITSELF WITHOUT THE USE OF THE WIND OR BEATING ITS WINGS

[*Diagram*]

When the centre of gravity of the bird is in front of the centre of resistance of the wings the bird will then descend by a slanting line always observing this slant.

The bird's descent will be found to be of swifter movement when the slant is less.

That bird travels with the longer course when its descent is interrupted by many reflex movements, that is in waves, as is shown above; let us say that the movement of the bird is so arranged as to go from *a* to *b*, and when it has travelled half a mile it makes in *c d* as great reflex movement as gives the nature of the impetus of such descent, and then brings back its wings to their first slanting position and descends afterwards in another movement of half a mile, and then rises up again and reascends until it finishes its course at the place indicated.

[*Diagram*]

If the bird which does not beat its wings should not wish to descend rapidly to a depth, then after a certain amount of slanting descent it will set itself to rise by a reflex movement and to revolve in a circle, mounting after the manner of the cranes when they break up the ordinary lines of their flight and come back into a troop and proceed to raise themselves by many turns after the manner of a screw, and then, having gone back to their first line they follow their first movement again which drops with a gentle descent, and then return again to a troop and moving again in a circle raise themselves.

[*Diagram*]

The bird which takes longer strokes with one wing than with the other will progress with a circular movement.

C.A. 220 V. C

With wings expanded the pelican measures five braccia, and it weighs twenty-five pounds; its measurement thus expanded therefore is the square root of the measurement of the weight.

The man is four hundred [pounds] and the square root of this figure is twenty; twenty braccia therefore is the necessary expanse of the said wings.

The width of the wings of the pelican is three quarters of a braccio, so you will divide the five braccia which it measures when open into quarters, so that there are twenty quarters in its length and three

FLIGHT OF BIRDS. COMPOSITE CIRCULAR MOVEMENT

MS. Codice Atlantico 308 *r.b.*

[Text: I. 454-5]

quarters in its width, and you may say that the width is three twentieths of the length.

If therefore the span of the man's wings be twenty braccia you would say that they are also three braccia in width, and three twentieths of this length of twenty braccia, that is, where the width is greatest.

C.A. 302 r. b

The imperceptible fluttering of the wings without any actual strokes keeps the bird poised and motionless amid the moving air.

The reverse movement against the direction of the wind will always be greater than the advancing movement; and the reverse movement when made with the course of the wind will be increased by the wind, and will become equal to the advancing movement.

The ways in which birds rise, without beating their wings but by circles, with the help of the wind, are of two kinds, simple and complex. The simple comprise those in which, in their advancing movement, they travel above the flight of the wind, and at the end of it turn and face the direction of the wind, receiving its buffeting from beneath, and so finish the reverse movement against the wind.

The complex movement by which birds rise is also circular, and consists of an advancing and reverse movement against the direction of the wind in a course which takes the form of a half circle, and of an advancing and reverse movement which follows the course of the wind.

The simple circular movement by which birds rise is also circular, and consists of an advancing and reverse movement against the direction of the wind in a course which takes the form of a half circle, and of an advancing and reverse movement which follows the course of the wind.

The simple circular movement of rising without beating the wings will always occur when there is great agitation of the winds, and this being the case it follows that the bird in so rising is also carried a considerable distance by the force of the wind. And the complex movement will be found to occur when there are light winds, for experience shows that in these complex movements the bird rises through the air without being carried too far by the wind in the direction in which it is travelling.

The down and feathers underneath the wings are plentiful, and at the ends of the wings and tail the tips of the feathers are flexible or capable of being bent, whilst those on the front of the wing, where it strikes the air, are firm.

C.A. 308 r. b

My opponent says that he cannot deny that the bird cannot fall either backwards or with head underneath in a perpendicular line; but that it seems to him that its descent may be sheer if it keeps the wings wide open and has one of the wings as well as the head below its centre of gravity.[1] To this argument the answer is the same as to what preceded it; that is, that if this bird being in such a position without having other means of aiding itself were to drop perpendicularly, it would be contrary to the fourth part of the second book of the Elements, where it was proved that every body which falls freely through the air will fall in such a way that the heaviest part of it will become the guide of its movement; and here the heaviest part is found to be midway between the extremities of the open wings, that is midway between the two lightest parts, and therefore, as has been proved, such a descent is impossible.

We have therefore proved that when a bird has its wings spread out and its head somewhat raised, it is impossible for it ever to fall or descend in a perpendicular line; on the contrary, it will always descend by a slanting line, and every tiny movement of wings or tail changes the direction and slanting descent of this line to the reflex movement.

Nature has so provided that all the large birds can stay at so great an elevation that the wind which increases their flight may be of straight course and powerful. For if their flight were low, among mountains where the wind goes wandering and is perpetually full of eddies and whirlwinds, and where they cannot find any spot of shelter by reason of the fury of the icy blasts among the narrow defiles of the mountains, nor can so guide themselves with their great wings as to avoid being dashed upon the cliffs and high rocks and trees, would not this sometimes prove to be the cause of their destruction? Whereas at great altitudes whenever through some accident the course of the wind is changed in any way whatsoever the bird has always time to redirect its course, and in safety take a calm flight, which will always be entirely free; and it can always pass above clouds and thereby avoid wetting its wings.

Inasmuch as all beginnings of things are often the cause of great results, so we may see a small almost imperceptible movement of the rudder to have power to turn a ship of marvellous size and loaded with a very heavy cargo, and that, too, amid such a weight of water as presses on its every beam, and in the teeth of the impetuous winds which are

[1] The MS. has here an explanation of a diagram: 'that is, it will drop in the line *a b*, the wings *d c* being wide apart at their natural extension'.

enveloping its mighty sails. Therefore we may be certain in the case of those birds which can support themselves above the course of the winds without beating their wings, that a slight movement of wing or tail, which will serve them to enter either below or above the wind, will suffice to prevent the fall of the said birds. C.A. 308 v. b

The thrushes and other small birds are able to make headway against the course of the wind, because they fly in spurts; that is they take a long course below the wind, by dropping in a slanting direction towards the ground, with their wings half closed, and they then open the wings and catch the wind in them with their reverse movement, and so rise to a height; and then they drop again in the same way. C.A. 313 r. b

When the slanting movement of the bird as it drops against the wind makes the weight of the bird more powerful than the wind that strikes it in front, the movement of this bird will become swift against this wind.

The bird which descends under the straight approach of the wind turns the wing somewhat over from the shoulder to the tip; and it does this in order to have as much leverage as possible in the more slanting movement against the wind. C.A. 353 r. c

The swallow has its wings quite different from those of the kite, for it is very narrow in the shoulder and long in the span of the wing. Its stroke when it flies is made up of two distinct actions, that is the span of the wing is spread out like an oar in the direction of the tail, the shoulder towards the earth; and in this way while the one movement impels it forward the other keeps it at its height, and the two combined carry it a stage onward wherever it pleases. C.A. 369 r. a

The movement of the air against a fixed thing is as great as the movement of the movable thing against the air which is immovable.

And it is the same with water which a similar circumstance has shown me to act in the same way as does the air, as with the sails of ships when accompanied by the lateral resistance of their helm. C.A. 395 r. b

[*Of the flight of the bat and of the eagle*]

I say that if the bat weighs two ounces and measures half a braccio

with wings expanded the eagle ought according to this proportion to measure with wings expanded not less than sixty braccia, and we see by experience that its breadth is not more than three braccia. And it would seem to many who neither see nor have seen similar creatures that one of the two would not be able to fly, considering that if there exists the proper proportion between the bat's weight and the breadth of its wings then in the case of the eagle they are not large enough, and if the eagle is properly equipped the other has them too large and they will be inconvenient and unsuitable for its use. We see however both the one and the other borne with the utmost dexterity by their wings, and especially the bat which by its swift turns and feints overcomes the rapid twists and retreats of the flies and gnats and other similar creatures.

The reason why the eagle supports itself with its small wings as the bat does with its large ones is contained in the comparison. . . .

When a single rush has the same proportion between its size and its length as a bundle of similar rushes has, it will in itself have the same strength and power of resistance as the said bundle. Therefore if the bundle has nine heads and supports nine ounces a single one of these similar rushes of which there are nine heads will by chance support one ounce.

Place on the top of a rush a *danaro*[1] as a weight and you will see it bend down as far as the ground. Take a thousand of these rushes and tie them together stretched out, fix them at the foot and make the heads level and load them; you will perceive that whereas by the first reason it ought to support about three and a half pounds it will in fact support more than forty.

So for this reason it follows that the expanse of air that supports the bat which weighs the two hundred and twentieth part of the weight of an eagle, if it had to be trodden down and pressed by the beating of the wings of the eagle would need to be sixty times larger.

B 89 v.

When a bird in beating its wings raises them higher above its centre of gravity than it lowers them beneath it it will have its head higher than its tail during its movement. This is proved by the fourteenth of this:— the movable thing will bend its straight movement more towards the side where its movement is less impeded than to that where it is more impeded; and by the eighth which says:— it is as much to move the air

[1] A small coin, about 20 grains Troy in weight.

against the immovable thing as to move the thing against the immovable air. Therefore the wing when it moves farther downward than upward makes more percussion with the air that borders on it below than with that which touches it above; and for this reason its straight movement will slant upwards.

If the bird while moving its wings an equal distance below and above its centre of gravity moves them more rapidly downwards than upwards it will curve its level movement upwards. This is proved by the ninth of the foregoing which said:— Of the equal movements made by the wings of birds those which are the most rapid will have most power to compress the air which borders on them below; and by the seventeenth which says:— the percussion of a movable thing is more deflected which has struck against a spot that offers more resistance; therefore it is concluded that if the wing making equal movement downward and upward moves down more rapidly than up it will curve its level movement upwards rather than downwards.

And by the converse of what has gone before if the wings while making equal movement below and above the bird's centre of gravity should rise more swiftly than they fall, the bird's movement will slant inclining towards the ground.

E 21 V.

The inclination of the wings of birds desiring to move with equidistant movement to the earth must necessarily always produce as much more fatigue when moving downwards than upwards, as the bird weighs more downwards than in the movement of equality. This is proved by the thirteenth of this where it is said: — the weight of every heavy thing is in the line of its movement and so much more or less as this movement is swifter or slower.

Definition of impetus

Impetus is a power created by movement and transmitted from the mover to the movable thing; and this movable thing has as much movement as the impetus has life.

The wings of birds feel as much more effort downwards than upwards when the bird wishes to rise upwards, in proportion as the bird weighs more downwards than upwards.

E 22 r.

A bird supporting itself upon the air against the movement of the

winds has a power within itself that desires to descend, and there is another similar power in the wind that strikes it which desires to raise it up.

And if these powers are equal one to the other so that the one cannot conquer the other, the bird will not be able either to raise or lower itself, and consequently will remain steady in its position in the air.

This is proved thus: — let *m* be a bird set in the air in the current of the wind *a b d c*. As this wind strikes it under the slant of the wing *n f* it comes to make a wedge there which would bear it upwards and backwards by a slanting movement if it were not for the opposing power of its weight, which desires to drop down and forward, as is shown by its slant *g h*, and since powers that are equal to each other do not subdue but offer a complete resistance the one to the other, for this reason the bird will neither raise itself nor lower itself; therefore it will remain steady in its position.

[*Figures*]

If the bird shown above lowers its wings it makes itself more stable upon the air and supports itself with less difficulty, because it occupies more space by keeping its wings in a position of equilibrium than in either lowering or raising its wings. In keeping its wings high however it cannot bend them either to the right or the left with the same ease that it would if it kept them low. But it is more certain not to be overturned in keeping its wings high than in keeping them low and bending them less to the right or the left, because as it lowers itself on the right side, through using its tail as a rudder, there is an increase of resistance, because the wing embraces more air than the other wing on the side on which it descends abruptly in returning to a position of equilibrium. Consequently it is a good expedient to descend with a straight and simple slant, and this it would not be able to do if it held its wings lower than its body, for if it were to bend itself about one of its sides by using its tail as a rudder it would immediately turn upside down, the wing that is farther extended embracing more air and offering more resistance to the slanting descent than the other.

E 22 V.

The extremities of the wings bend much more in pressing the air than when the air is traversed without the beating of the wings.

The simple part of the wing is bent back in the swift slanting descent of the birds. This is proved by the third of this which says: — among

things which are flexible through the percussion of the air, that will bend most which is longest and least supported by the opposite side.

Therefore the longest feathers of the wings not being covered by the other feathers that grow behind them and not touching each other from their centre to their tip will be flexible, and by the ninth of this which said: — of things equally flexible that will bend the most which first opens the air. And this we shall prove by the eleventh which says: — of equal and similar things bent by the wind that will bend the most which is struck by air of greater density.

The helms placed on the shoulders of wings are extremely necessary for it is these parts which keep the bird poised and motionless in the air facing the course of the winds.

[*With drawing of wing*]

This helm *a* is placed near the spot where the feathers of the wings bend, and through being very strong it bends but little or not at all, being situated in a very strong place and armed with powerful sinews and being itself of hard bone and covered with very strong feathers, one of which serves as a support and protection of the other. E 23 r.

Simple slant

If the slanting movement of the bird be made simply according to the direction of its length this slant will be rectilineal.

Compound slant

But if to the slant of the length of the bird there be added the slant of the breadth of its open wings the movement of this bird will be curved, and the curve will have its concave side in the direction of the lower wing.

Irregular movement

And if the bird is struck by the wind on the tip of its lower wing its compound movement with its slanting curve will become broken and will merely form a straight slant.

The wing of the bird is always concave in its lower part as far as the part that extends from the elbow to the shoulder, and in the rest it is convex.

In the concave part of the wing the air is whirled round, and in the convex it is pressed and condensed. E 23 v.

WHY THE BIRD MAKES A REVOLVING MOVEMENT BY BENDING ITS TAIL

All the bodies that have length and move through the air, with their lateral extremities equidistant from the central line of their bulk, will make straight movements; the power of the impetus which impels these bodies varying neither in the natural movement nor even in the violent or the semi-natural movement.

If however the lateral extremities of the bodies that have length are at an uneven distance from the central line of their bulk the movement of the body will form a curve in the air as it moves; and such curve will have its concave part on the side on which the extremity of the body mentioned is more remote from the said central line.

Concerning complex slants in birds' flight

A complex slant is said to be that which birds make when they move in the air keeping their tail higher than their head and one wing lower than the other.

When a bird flies in a complex slant the movement in the one slant will be so much swifter than in the other as the one is less oblique than the other.

The movement made by birds that fly with a complex slant is curved.

The curve created by the complex movement made by birds as they fly will be greater or less as the lateral slant is less or greater.

E 35 v.

The flight of birds has but little force unless the tips of the wings are flexible. This is proved by the fifth of the Elements which says: — lateral power checks the descent of heavy things; as may be seen in the case of a man pressing with his feet and back against two sides of a wall as one sees chimney sweepers do. Even so in great measure the bird does by the lateral twistings of the tips of its wings against the air where they find support, and bend.

When the bird in its direct descent is struck by the wind under its wings this descent will become so much more slanting as the wind is of greater power. Proved by the ninth of this which says: — of direct descents which similar and equal heavy bodies make in the air that will slant most which is struck by the wind with most impetus.

If a bird fly with its wings at equal height and lower one of the sides of its tail its direct flight will become curved, and this curve will have its concave side towards the lowered side of the tail, and the wing on this

side will be as much slower than the opposite wing as the movement of the bird is more curved.

This is proved by the seventh of this which says: — that part of a wheel as it revolves will have least movement which is nearest to the centre of this revolution. As therefore the tip of the wing *a* touches *a*, the centre round which it revolves, it will have less movement, and the opposite wing will have its extremity *d* with the movement *g b*. E 36 r.

The descent of birds is of two kinds, of which one is with certainty upon a fixed position, the other is uncertain upon two positions or more. In the first its wings are open and the points are raised above the back, and with these at equal height it drops with straight simple slant to its appointed place. The second bird as it descends has the points of its wings held lower than the breast and bends its tail now to the right now to the left, with slant now simple now complex and sometimes irregular. [*Figure*]

The bird that is struck on its side by the wind moves the wing that is towards the wind with greater swifter motion than it does the other as the wind is more impetuous in its movement. This may be proved: — let *a b c* be the bird that moves along the line *a f* and to the wind *d*, which strikes it at the side on the wing *a b*, and would carry it along the line of its course if the wing *a b* was not swifter in its movement than the wind. And this is why when the wind has struck the side of the bird and by some eddying recoil has folded itself up against the wing which has closed itself by flapping, this wing has thus had a second support against the said bending of the straight movement of the bird. It must therefore be concluded that the wide swift movement, which the wing that is struck by the wind makes in excess of that made by the opposite wing, at the same time as the wind which has struck the bird and been bent back against the said wing, is that which prevents the straight course of birds from being deflected by the wind. And moreover unless the opposite wing was slow and of little movement it would strike into the course of the wind and the wind [would strike] against it; and thus the wind would be most powerful to accompany this bird in its course.

E 36 v.

WHY THE FLIGHT OF BIRDS WHEN THEY MIGRATE IS MADE AGAINST THE APPROACH OF THE WIND

The flight of birds when they migrate is made against the movement of the wind not indeed in order that their movement may be made more

swiftly but because it is more lasting and less fatiguing. And this comes about because with a slight beating of their wings they enter the wind with a slanting movement, this movement being below the wind. After this impetuous movement they place themselves slantwise upon the course of the wind.

This wind after entering under the slant of the bird after the manner of a wedge raises it up during such time as the acquired impetus takes to consume itself, after which it descends afresh under the wind and again acquires speed; then repeating the above-mentioned reflex movement upon the wind until it has regained the elevation that it lost, and so continuing in succession.

WHY BIRDS SELDOM FLY IN THE DIRECTION OF THE CURRENT OF THE WIND

It very seldom happens that the flight of birds is made in the direction of the current of the wind, and this is due to the fact that this current envelops them and separates the feathers from the back and in addition to this chills the bared flesh. But the greatest loss is that after the descent slantwise its movement cannot enter upon the wind and by the help of it be thrown back to the elevation it has left unless it has already turned backwards, which would not help it to make progress in its journey.

The bird spreads out the feathers of its wings more and more as its flight becomes slower; and this is according to the seventh of the Elements which says:—that body will become lighter which acquires greater breadth.

E 37 r.

A bird descending makes itself so much swifter as it contracts its wings and tail. This is proved by the fourth of Gravity, which says:—that heavy body makes a more swift descent which occupies a less quantity of air.

That bird is more rapid in its descent which descends by a less slanting line. This is proved by the second of Gravity, which says:—that heavy body is swiftest which descends by the shortest way.

A bird in descending lessens its speed more and more as it is more extended. This is proved by the fifth of Weight, which says:—that heavy body is most checked in its descent which is most extended.

A bird in making a reflex movement rises in proportion as it acquires greater breadth. This is proved by the fourteenth of Local Movement,

which says: — the heavy body that occupies a less space of air in the line of its movement penetrates it more rapidly. Therefore the widest expansion of the wings produces the greatest diminution in the bulk of the whole bird, and in consequence the impetus of its reflex movement is less impeded; and therefore it rises farther at the end of this reflex movement.

When the bird descends upon the spot where it wishes to settle, it raises its wings and spreads out the half of its length and so descends slowly upon the aforesaid low place.

E 37 v.

There is as much to move the air against the immovable thing as to move the thing against the immovable air.

When the bird moves with slow descent on a long course without beating its wings and the incline leads it more quickly to the ground than its intention is, it then lowers its wings and moves them against the immovable air, and this movement raises the bird up just as though a wave of wind struck it below: and this is proved by the last but one.

OF TWO CONTRARY SLANTS OF WHICH ONE IS DESCENDING AND THE OTHER IS A REFLEX MOVEMENT

The movement of the bird that descends by two contrary slants will be longer in proportion as the slant on which it rises more resembles the slant by which it descends.

This may be proved: — suppose that of itself the slant with which the bird descends makes a hundred miles an hour in order to descend to earth with a descent of a hundred braccia, and that the opposite slant along which it makes its reflex action at this time spares it the half of this descent, I affirm that the movement which was a hundred miles an hour will become fifty, as is proved in its place.

E 38 r.

Birds always fly more slowly when they raise their wings than when they lower them. This is caused by the necessary period of rest that is required after the adjacent fatigue of the tired limbs, and moreover speed is not necessary in raising these limbs as it is in lowering them, seeing that the impetus that carries the bird is generated through a long space of movement in this bird. It is sufficient merely for it to have raised its wings from where they first descended when the said impetus commences to decline, which reveals itself through the falling of the bird,

But when the bird wishes to acquire speed it resumes the impetus nearer to its inception and beats its wings more frequently and with the longest and most rapid movement possible.

OF THE CIRCLING MOVEMENT MADE BY THE KITE IN RISING

The circling movement made by birds as they rise above the wind is produced by the bird entering upon the wind with one of its wings, and balancing itself with the other in the direct line of the wind.

In addition to this it lowers one of the corners of its tail towards the centre of its circular movement, and because of this the wind that strikes it on the inside checks the movement of the side that is lower and nearer to the centre of this circle. And this is the cause of the circling movement, and the wing held above the wind causes the bird to rise to the maximum height of the wind.

E 38 v.

The simple movement which the wings of birds make is more easy when they rise than when they are lowered. And this ease of movement springs from two reasons of which the first is that the weight in falling somewhat raises the wings up of themselves, the second is due to the fact that owing to the wing being convex above and concave below the air flows away more easily from the percussion of the wings as they rise than when they are lowered, for then the air being pent up within the concavity of the wing becomes compressed more easily than it escapes.

OF THE EXPANSION OF THE TAIL IN THE REFLEX MOVEMENT OF BIRDS

Birds spread out their tails in their reflex movement because the air is compressed beneath them and resists the penetration of the bird in its maximum breadth, so that the impetus is consumed with just the edge or front of the wing. If this were not so the impetus acquired in the falling movement would consume itself partly in the direction of the earth and partly in the reflex movement; and then this reflex movement would be as lacking in height as that which drops down by keeping the tail straight.

The bird acquires more lightness the more it spreads itself out and expands its wings and tail.

That heavy body shows itself lightest which extends in greatest breadth,

From this conclusion one infers that by means of a wide expanse of wings a man's weight can support itself in the air.

That body shows itself less heavy which extends in greater breadth.

E 39 r.

OF THE CAUSE OF THE CIRCULAR MOVEMENT OF BIRDS

The circular movement of birds is produced by the unequal movement of their wings, and this is caused by the percussion created in the air by one of the corners of the tail that projects above or below the route made by the bird in the air traversed by it.

Of the things that are moved by others with simple movement the thing moved is as swift as the swiftness of its mover: therefore the bird carried by the wind in the same direction as this wind will have a speed equal to it.

But if the objects carried by the wind slant more towards the ground than the direction of the course of this wind the thing moved will be swifter than its mover. And if the slant of the objects carried by the wind turns towards the sky this is a clear sign that the movement of the thing moved is slower than that of the wind. The reason is that when the slant is turned towards the ground it produces this movement by reason of its gravity and not by the help of the wind. But when the slant of the movement made by the thing moved is towards the sky, this slant is caused merely by the shape of the thing moved, for it bears itself like a leaf which caught by the wind in its breadth raises itself up merely by the help of the wind, and moves as much as its mover, as has been shown in its place.

E 39 v.

When the bird is driven by the wind and has a more slanting course than the course of the wind it is so much swifter than the said wind.

When the bird driven by the wind has its movement parallel to that of the wind it also has a speed equal to that of the wind.

When birds are driven by the wind without beating their wings the bird is swifter than the wind in proportion as its course is more slanting than that of the wind. This is proved as follows: suppose the wind in a position of equality to move one degree of space in one degree of time and the bird driven by the same wind to move the same degree in the same time, these movements up to this point will be equal. But on account of the slant in the bird's movement let us assume it to acquire a

second degree of movement in the same time that the wind is acquiring its first degree; it follows therefore that the bird in the same time can be twice as fast as the wind that drives it.

But this same slanting movement does not acquire its distance within a position of equilibrium, but between this position of equilibrium and the centre of the earth, as if the position of equilibrium was the line *a c* along which the wind moves from *a* to *c*, and the bird moves by the help of the wind and by help of its gravity from *a* to *d*. I say that in the same time in which the bird shall be moved (without the help of its gravity) from *a* to *b*, it will be moved by the help of the wind and of its gravity from *a* to *d*, the one movement being in the proportion of one and a half as compared with the other, from *a* to *d* upon the movement *a b*. But as regards the distance of the aspects, *a d* is the same as *a b*, as is shown us by the perpendicular *b d*.

E 40 r.

OF BIRDS WHICH FLY IN COMPANIES

When the birds which fly in companies come to make long journeys, and the wind chances to strike them on one side, they are greatly helped in their flight because the flight is made in loops without working their wings; because the falling movement is made beneath the wind, with the wings somewhat close together, and in the direction in which they are travelling. But the reflex movement is made above the wind; and with the wings held open it rises up as the wind meets it, and consequently, the wind entering beneath the bird lifts it up towards the sky, after the manner of a wedge, when it penetrates beneath a heavy body which is set above it. By this means, after the birds have been lifted up to their proper height, which is the equivalent of that at the beginning of the falling movement, they return to their first course, recommencing always in this course their falling movements; and their reflex movements are always made against the wind.

E 40 v.

OF FLYING THINGS

Before birds start on long journeys they wait for the winds favourable to their movements, and these favourable winds are of a different kind with different sorts of birds, because those which fly in jerks or bounds are obliged to fly against the wind, others receive the wind on one of their sides at different angles and others receive it on both sides. But the birds that fly by jerks such as fieldfares and other birds like these which

fly in companies, have the feathers of their wings weak and poorly protected by the lesser feathers which form a covering for the larger ones. And this is why it is necessary that their flight should be against the course of the wind, for the wind closes up and presses one feather upon another and so renders their surface smooth and slippery when the air tries to penetrate it. It would be the contrary if the wind were to strike these birds towards the tail, because then it would penetrate under each feather and turn them over towards the head, and thus their flight would have a confused movement, like that of a leaf blown about in the course of the winds which goes perpetually whirling through the air continually revolving, and in addition to this their flesh would be without protection against the buffeting of the cold winds. And in order to avoid such accidents they fly against the course of the wind with a curving movement, and their bounds acquire great impetus in their descent, which is made with wings closed under the wind. And the reflex movement proceeds with wings open above the wind, which brings the bird back to the same height in the air as that from which it first descended, and so it continues time after time until it arrives at the desired spot.

The reflex movement and the falling movement vary in birds in two ways, of which one is when the reflex movement is in the same direction as the falling movement, the second is when the reflex movement is in one direction and the falling movement is in another.

The bird in the falling movement closes its wings and in the reflex movement it opens them: it does this because a bird becomes heavier in proportion as it folds its wings and so much lighter as it opens its wings more.

The reflex movement is always made against the wind and the falling movement is made in the direction in which the wind is moving.

E 41 r.

If the flight of the bird turns to the south without beating its wings when the wind is in the east, it will make the falling movement rectilinear with its wings somewhat contracted and underneath the wind. But the reflex movement which succeeds this falling movement will be with the wings and tail open and it will have been directed towards the east.

At the end of this movement it will turn its front back again to the south and with its wings folded it will create again the succeeding falling movement which will be of the same nature as the first, desiring to make a long course with the help of this wind; and the junction of the falling

movement with the reflex movement will always be of the nature of a rectangle, and so will be that of the reflex movement with the falling movement.

There are two ways in which the wind causes birds to become stationary in the air without beating their wings.

The first is when the wind strikes against the sides of steep mountains or other rocks by the sea, as the bird then sets itself at such an angle that it carries in front as much of its weight against the reflex wind as this wind in front has power in its resistance. And since equal powers cannot prevail over each other it follows that in such a position a bird through its imperceptible vibration remains motionless. The second way is when the bird sets itself at such a slant above the course of the wind that it has as much power to descend as the wind has to resist its descent.

When by the help of the wind the bird rises without beating its wings and makes a circular movement, and when it spreads its tail at the uprising of the wind, it is being driven by two powers, one of which is that of the wind which strikes the wings in the hollow beneath them and the other is the weight of the bird which is descending by a complex slant. And from the fact of its acquiring such velocity it comes to pass that as it turns its breast to meet the onset of the wind this wind acts under the bird after the manner of a wedge which lifts up a weight; thus the bird makes its reflex movement much higher than the commencement of its falling movement; and this is the true cause why birds rise some distance without beating their wings.

E 41 V.

DEFINITION OF THE MOVEMENTS

Straight movement is that which extends from one point to another by the shortest line.

Curved movement is that in which there is found some part of straight movement.

Spiral movement is formed out of slanting and curved lines in which the lines drawn from the centre to the circumference are all found to be of varying length, and it is of four kinds, namely convex spiral, level spiral and concave spiral and the fourth is a spiral in cylindrical form. There is also the circular movement always made round about a point at equal distance, which is said to be revolving, since there are there irregular movements which although they are infinite are made up of a blend of each of the aforesaid movements.

The commencement of the simple falling movement is always higher than the termination of its simple reflex movement, the mobile generator of these movements being immobile in the air.

But the complex falling movement in conjunction with the complex reflex movement will have the contrary result to the simple, provided that the falling movement is lower than the reflex movement, and this arises out of the fact that the bird which below the wind creates this falling movement presses down and lowers the course of this movement; but the reflex which is produced above the wind with wings open raises it considerably higher than the commencement of this falling movement.

E 42 r.

DEFINITION OF THE WAVES AND IMPETUS OF THE WIND AGAINST FLYING THINGS

The bird maintains itself in the air by imperceptible balancing when near to the mountains or lofty ocean crags; it does this by means of the curves of the winds which as they strike against these projections, being forced to preserve their first impetus bend their straight course towards the sky with divers revolutions, at the beginning of which the birds come to a stop with their wings open, receiving underneath themselves the continual buffetings of the reflex courses of the winds, and by the angle of their bodies acquiring as much weight against the wind as the wind makes force against this weight. And so by such a condition of equilibrium the bird proceeds to employ the smallest beginnings of every variety of power that can be produced.

Of the movement and the eddies made by the current of the air striking upon various projections of the mountains, and how the birds steer themselves in the various tempests of the winds by the imperceptible balancing of their wings and tail:

The falling movement is always united with the reflex movement and the beginning of the reflex movement is united with the end of the falling movement; and if such movements form a continuous succession always following each other, one will be the cause of the other, and the death of one will immediately produce the other, so that they will never both exist at the same time; and the falling movement has a weak beginning and is continually increasing and the reflex movement is the opposite.

HOW THE TAIL OF THE BIRD IS USED AS A RUDDER

When the bird lowers its tail equally it descends by a straight slanting movement. But if it is more lowered on the right side then the straight line of the descent will become curved and will bend towards the right side with a greater or less curve of movement in proportion as the right point of the tail is higher or lower, and if the left point of the tail is lowered it will do the same on the left side.

But if the tail is raised equally a little above the level of the back of the bird it will move along a straight line slanting upwards; but if it raises the right point of the tail more than the left this movement will be curved towards the right side, and if it raises the left point of the tail this straight movement will curve on the left side.

E 42 V.

When two movements of impetus meet, the percussion is more powerful than if they were without encounter. As therefore the impetus of the bird encounters the impetus of the wind its simple impetus increases and the reflex movement is greater and higher.

The bird moves against the wind without beating its wings and this is done beneath the wind as it descends, and then it makes a reflex action above this wind until it has consumed the impetus already acquired, and here it is necessary that the descent should be so much swifter than the wind that the death of the acquired impetus at the end of the reflex movement may be equal to the speed of the wind that strikes it below.

WHY SMALL BIRDS DO NOT FLY AT A GREAT HEIGHT AND LARGE ONES DO NOT LIKE TO FLY LOW

This arises from the fact that the small birds being without feathers cannot endure the intense cold of the great height of the air at which fly eagles and other large birds which have more power of movement and are covered with many rows of feathers. Also the small birds having feeble and simple wings support themselves in the lower air which is thick and would not support themselves in the rarefied air which offers less resistance.

The end of the reflex movement is much higher (for the birds which fly against the wind) than the beginning of their falling movement; and

by this Nature does not break her own laws, and this is shown by what has gone before.

E 43 r.

HOW THE BIRD RISES BY MEANS OF THE WIND WITHOUT BEATING ITS WINGS

The bird rises to a great height without beating its wings by means of the wind, which strikes it in a great mass underneath its wings and tail placed slantwise and above its back placed at an opposite slant.

This may be proved: — suppose the wind compressed beneath the bird to have the same effect beneath it that one sees happening when a wedge is driven beneath a weight, for the wedge at each degree of its movement causes the weight to acquire a degree of height. But since the opposite slant of the body which the bird has is disposed to descend against the approach of the wind with the same power as that with which the wind raises it up, through the slant of the body being contrary to that of the wings, it is covered as much.

[*A drawing of a sector*]

Here it is necessary to calculate the degrees of the slant, for in no degree of slant either of an object upon the water or a bird in the air do they stop, but their speed will be greater or less as their position slants less or more.

The bird weighs less which spreads itself out more, and conversely that weighs more which draws itself together more tightly; and the butterflies make experiments of this in their descents.

E 43 v.

HOW THE BIRD FALLING HEAD DOWNWARDS HAS TO GUIDE ITSELF

The bird that falls head downwards guides itself by bending its tail towards its back. This is proved by the tenth which says: — the centre of a heavy object that descends in the air will always remain below the centre of its lightest part. Therefore as *c d* the central line of the gravity of the bird is at a distance from *a b* the central line of the levity of the tail of this bird, the two lines will necessarily form the same line over a short space of the descent of this bird. And this being so one must needs admit that the direct descent will of necessity become a slant and in becoming a slant the descent will be as much slower as the movement is longer, or that the movement will be as much longer as the descent is slower, and as much longer and slower as the descent is more slanting.

HOW THE BIRD STEADIES ITSELF AS IT FALLS BACKWARDS

But if the bird turns over in the air because of the wind the tail ought to close up as much as it can and the wings rise behind the head. And with the part in front of the centre it becomes heavy and with that behind light, the centre of gravity not being in the centre of its volume; and by the ninth which says: — the fact that the centre of the volume is not concentric with the centre of gravity is the reason why the body in which these centres are contained will never remain in a state of equilibrium with its greatest breadth; and by the tenth of this: — the centre of the gravity of bodies suspended in the air will always be below the centre of the volume of the same bodies.

E 44 r.

Why the bird makes use of the helm placed in the front of the wings although it has other ways of curving its straight movement:

The bird only makes use of one of the helms placed in the front of its wings when it wishes to bend its straight movement into a level position.

When however it comes to pass that this bending process is complex, that is it is a slanting curve, it will then draw in one of its wings a little, and thus will make a curved movement which will descend on that side on which the wing is drawn in, showing there the convex movement.

But such a process as this involves the danger of its turning over on its side and leaving the point of the wing extended towards the sky, and as a means of protection against this it is necessary to extend the wing that is drawn in, always showing the under side of the wing to the ground, for if you were to show it the right side the bird would turn upside down. When therefore in these conditions you have extended the folded wing towards the ground you will at the same time gather up the upper wing which was extended, until such time as you return to a position of equality.

In having shown one of the dangers which occur to deflect the straight movement of the birds in the air, by disturbing the equal resistance which wings make when they are equally open upon the air and have their centre of gravity between them midway between their extremities, we have at the same time proved that it is safer to bend one of the two helms of the wings than it is to bend one of the two wings.

E 44 v.

WHICH OF THE MOVEMENTS OF THE WINGS IS THE SWIFTEST

The movement of the wings is twofold inasmuch as part of the movement descends towards the earth and part towards the place from whence the bird is flying. But that part of the movement which is made towards the earth checks the bird's descent and the backward movement drives it forward.

What it is in the bird that causes it to bend its straight movement without it either descending or raising itself:

The bird bends its straight movement made in a position of equilibrium without raising or lowering itself, by means of the right or left helm placed in the front part of the wings. This is proved thus: let *a p o g* be the bird which moving in a position of equilibrium bends the straight movement *m p a* to the curving movement *a b* by means of the helm *t* which is set in the front part of the left wing, and this comes about by the ninth of this which says: — the bodies with equal sides about the central line of their gravity will always keep the straight line of their movement in the air — and if the volume of one of the sides is increased or diminished the straight movement will describe a curve, showing the concave part of the curve on the side of the greater inequality of the thing that is moved.

E 45 r.

OF THE UNDERSIDE OF THE WINGS [*with drawing*]

They form coverings one to the other *b* to *a*, the resisting parts of the feathers beneath the wings of the birds behind the flight of the air or wind, so that this air or wind shuts up a part of the feathers that offer weak resistance upon the opposite feathers which offer powerful resistance.

WHY THE FEEBLE RESISTANCES ARE BENEATH THE POWERFUL ONES

The feathers that offer a feeble resistance are set beneath those which offer a powerful resistance with their extremities turned towards the tail of the bird, because the air underneath flying things is thicker than it is above them and in front than it is behind; and the necessity of flight brings it about that these lateral extremities of the wings are not found by the stroke of the wind because then they would immediately become spread out and separated one from another, and would be instantly penetrated by the wind. Consequently these resistances being so

placed that the parts which have a convex curve are turned towards the sky, the more they are struck by the wind the more they lower themselves and draw closer to the lower resistances with which they are in contact, and so prevent the entry of the wind beneath the front of the lateral parts of these resistances.

WHAT TEXTURE OF AIR SURROUNDS BIRDS AS THEY FLY

The air which surrounds the birds is as much lighter above than the ordinary lightness of the other air as it is heavier below, and as much lighter behind than above as the bird's movement is swifter in its transverse course than is that of its wings towards the ground, and similarly the heaviness of the air is greater in front of the contact of the bird than below it in proportion to the two above mentioned degrees of lightness of the air.

The straight movement of birds in the air forms a curve towards the side on which the wing is drawn together, and this arises entirely out of the fact that every heavy body descends on that side on which it has less resistance; this movement therefore may be described as a complex curve formed out of a lateral curve and the declining curve made by the bird upon that side which is lower than itself.

E 45 V.

OF RAISING AND LOWERING THE WINGS

Birds raise their wings when open with greater ease than they lower them. And this is proved by the third of this which says: — parts of bodies which are convex are more suitable for penetrating the air than those which are concave.

It follows that as birds have their wings convex on the side that is uppermost and concave on the side below they will raise their wings with greater ease than they lower them.

OF THE SPREADING OUT OF THE FEATHERS AS THE WINGS ARE RAISED

The feathers spread out one from another in the wings of birds when these wings are raised up, and this happens because the wing rises and penetrates the thickness of the air with greater ease when it is perforated than when it is united.

OF THE CLOSING UP OF THE FEATHERS AS THE WINGS ARE LOWERED

The spaces between the feathers in the wings of birds contract as the wings are lowered, in order that these wings by becoming united may prevent the air from penetrating between these feathers, and that with their percussion they may have a more powerful stroke to press and condense the air that is struck by these wings.

OF THE RESISTANCES OF THE FEATHERS IN THE WINGS OF BIRDS

The resistances of the feathers in the wings of birds form with their powerful curves shields one of another in the upper part against the penetration of the air or the onset of the wind, so that this wind may not as it enters cause them to spread themselves out and raising open them and so separate the feathers one from another.

It is shown here below how as the feathers under the wings in order to support themselves have to rest and rub themselves upon the air which sustains them, part of the resistance that there is in the feathers remains beneath the strong part of the other feathers, for the feathers underneath the wings have their long weak portions situated underneath the short strong parts of the next row of feathers.

Why the sinews beneath the birds' wings are more powerful than those above. It is done for the movement:

The shoulder where the helm of the wing is placed is hollow below after the manner of a spoon, and being thus concave below it is convex above. It is fashioned thus in order that the process of rising may be easy and that of lowering itself difficult and may meet with resistance, and especially it is of use to go forward drawing itself back in the manner of a file.

E 46 r.

OF THE EXTREMITIES OF THE WINGS WHEN RAISED

The extremities of the wings when raised to their maximum height are farther away from each other than when lowered as far as possible.

And when these wings re-ascend their extremities continue the descent that has been begun until they straighten the curve that they have formed, and then bend in the opposite curve and continue it nearly to the end of their elevation; and as the wings recede from this elevation

the extremities pursue the elevation that has been begun until the first curve has been destroyed and another has been formed in the contrary direction.

In the impetus made in the air by the birds it is better and easier to bend a part of the wings than the whole. The part of the bird which bends in the air will cause the whole of it to bend, as one sees happen to a ship through the turning of its rudder.

By what has been said above the points of the wings produce a greater movement than is demanded by their length since they are not flexible. This is proved:—let there be the movement of the points of the wings which are flexible *a c* and of those which are not flexible *b d*; the movement *a c* of the flexible extremities of the wings exceeds *b d* the movement of the non-flexible wings, and of these two lines of movement the one is proved to be less than the other because the one is part of the other.

But because the points of the wings as they are raised and lowered make a less movement than the parts of the feathers joined to them, and before these points of the wings commence to extend the parts of the feathers united to these points they turn in a contrary movement, it is necessary for part of the extremity of these feathers to turn back with the rest of the feather, and for the point to come forward like a finger that raises itself as much as the hand descends, which finger one would describe as immovable because it does not change its position; and for this reason we may say that the point of the flexible wing has a movement resembling that of the wings that are not flexible.

E 46 v.

WHETHER THE CURVES OF THE END PARTS OF THE WINGS ARE NECESSARY OR NOT

The air which is underneath the curves of the end parts of the wings as they descend is more compressed than any other portion of the air that is found underneath the bird, and this is brought about by the beating of the wings. This is proved by the seventh which treats of percussion, where it is stated that percussion is greater in proportion as the movement of that which strikes is more long continuing. Therefore in the case of the whole wing descending at the same time that part has most rapid movement which is most distant from the fixed part, and as a consequence that air is most compressed which is struck by the swiftest

blow. It follows also that the flexion of the point of the wing is after the manner of a spring or a bow bent by force, and that this process of bending compresses the air with which it comes in contact.

But when these wings rise up their points follow the line of their descent until they straighten themselves and then they bend back in the opposite direction, that is that if the concavity which there is in the end of the wing as it descends turns towards the sky the concavity of the same end as the wing rises will be turned towards the earth.

That part of the shaft is most rapid which is furthest away from its motive power, and the proportion of speed to speed is as the distance, the shaft as it moves not bending.

E 47 r.

If the movement of the wind had uniform power in its expanse the bird would not be so often engaged in beating the wind and balancing itself with its wings.

The air in itself is capable of being compressed and rarefied to an infinite degree.

WHETHER THE FOLDS IN THE EXTREMITIES OF THE WINGS ARE NECESSARY OR NOT

The curve which is created in the extreme parts of the wings when these wings strike and press upon the air which is condensed beneath them has the effect of greatly increasing the bird's power of flight, for in addition to pressing on the air that is below them they compress the adjacent lateral air, by the fourth of the second which says 'every violence seeks to undo itself on the very lines of the movement which has produced it'; and by the seventh 'every straightness which is bent by force has the lines of its power converging in the centre of a complete circle formed by the curve commenced by this extremity of wing'. As if the wing *a b c d* being curved at its extremity *c d b*, I come to finish the circle *c d b r* of which the centre is *n*, and from this I draw the line *n f* touching the point of the wing; and the others will be the lines *n e* and *n f*, and thus in the centre are the infinite images of the others.

And by what is said below all these lines have the same boundaries as the curve of the wings *b d c* by the rule of the perpendicular; therefore the force of this extremity of wing *b d c* is directed along the lines *b f*, *d e*, *c m*, and of these *b f* is outside the space occupied by the bird as the line *b o* informs us.

E 47 v.

OF FLYING THINGS

If the lateral parts change from a position of equilibrium the straight slanting movement will change to a curved slanting movement.

The bird which after its descent is thrown back in the air will never regain its former height unless it beats its wings and has the help of the wind.

The bird that drops down before the approach of the wind with a straight slant will always have its reflex movement more raised than its falling movement.

The curving slant that is seen to occur when birds are flying to meet the approaching wind with a falling reflex movement is much more steady than the same movements made in a straight slant.

OF REFLEX WINDS

If the birds are driven by the wind without beating their wings and the wind meets the wall set over against it, in avoiding this wall [the bird] immediately encounters the reflex wind.

If the bird moves towards the north upon the wind and the wind wishes to turn it to the east, the bird in order not to spoil the equal expanse of wing which keeps it at its maximum levity will lower the right tip of the tail and receive the stroke of the wind upon it more than it does upon the left tip, keeping thus its straight movement direct to the north upon the wind.

E 48 r.

OF THE THINGS THAT MOVE IN THE AIR AND THEIR DESCENT

A parallel board of uniform thickness and weight placed flat in a position of equality in uniform resistance will descend uniformly in each of its parts. And if this board is placed in the air in a slanting position the descent will slant uniformly, and this is proved in its place.

The shape of the front part or back part of the thing that moves in the air or water is what bends its straight course.

An irregularity attached either in front or behind the extremities of the equality that moves in the air is what diverts to right or left or up or down or in some slant the straight movement of the aforesaid equality.

A bird which descends with a straight slant in one direction will not change the equal position of its side parts.

A bird in the air makes itself heavy or light whenever it pleases; and it does this by spreading out its wings and expanding its tail when it wishes to check its swift descent, or by contracting wings and tail when it wishes to quicken a descent which has been delayed.

E 48 v.

The helms placed on the shoulders of the wings are [formed] of very strong feathers because they bear a greater strain than all the other feathers.

[*Figure*] *a b* the helms of the wings come into use when the bird is in swift descent. When it wishes to capture its prey and to turn from one direction to another without checking its movement it uses these helms, and if these were not there it would be necessary for it to employ the whole wing, and this by reason of its size would greatly hinder the movement commenced, contrary to its intention.

OF THE SLANTING MOVEMENT OF BIRDS

The bird which consumes the impetus against the coming of the wind with its wings open without any movement, except for their necessary balancing, if it finds itself above this wind, will always rise, but with greater or less increase of height as the impulse which moves it is of greater or less power and of less or greater slant in itself.

But if the bird moves without beating its wings underneath the wind the impetus will be consumed in the descent of the bird but the impetus will be the more permanent as the descent is less slanting.

If the bird moves with its wings open and without beating them, at the same time as the wind and in the same direction, this bird will then acquire a degree of descent with each degree of movement; but this descent will be as much more slanting as the wind is swifter, as is proved when heavy substances are thrown into running water.

And if a bird is struck behind and below by the wind then the bird will rise up, but this is only done on very rare occasions by birds, because such a movement turns the feathers over and down so that they point towards the head of the bird.

E 49 r.

OF EVERY KIND OF FLIGHT MAKE ITS OPPOSITE

When the bird is driven by the wind it proceeds continually to descend by a slanting movement, and when it desires to rise to its former

height it turns backwards and uses the impetus of the wind as a wedge.

Science

The impetus that the bird acquires by its falling movement may be reflected in each direction by a movement that is either straight or a gradual curve whichever it may be until this impetus is consumed.

Rule

When the bird struck beneath the right side by the wind desires to descend upon some spot it lowers the one of its wings upon the side where it wishes to settle.

Science

The bird that desires rapidly to consume the impetus it has acquired turns its wings in their full extent against the spot where it wishes to halt — and this it does without the help of the wind.

When a bird desires to rise straight up without the wind by means of beating its wings the turning movement is necessary.

But if the bird's movement is to be in a straight line without the help of the wind it is necessary that the movement should be made by frequent beatings of the wings, and for this cause the movement will be extremely slanting.

E 49 V.

THEORY OF FLYING THINGS

The movement made by a movable thing which is long in shape and of uniform sides round about its centre-line will take a straight course through the air for so long a time as the impetus lent to it by its mover lives within it.

The bird which flies in a curved line in a level position moves one wing with a longer and more rapid movement than the other, but such movement does not raise or lower the one wing more than the other.

But if the curved movement of birds is made up of curve and slant, then in addition to the movement in one wing being swifter and longer than in the other the one wing will also go higher and lower than the other. And this is proved by the fourth which says, 'wings of equal movement propel the bird in a straight line', and by the converse 'wings of which the movement is unequal in length make a curved movement'.

And if the movement of wings which are unequal is of equal height but of varying length the movement of the bird will then be a curve in a level position. And if the movement of the wings in addition to being unequal in length is also unequal in height and depth, this being more in the case of one wing than the other, this movement is composed of curve and slant.

E 50 r.

OF THE REVOLVING MOVEMENT

[*With three sketches of a top spinning*]

The pegtop or 'chalmone' which by the rapidity of its revolving movement forgoes the power that comes from the inequality of its weight round the centre about which it revolves, on account of the impetus that controls this body, is a body which will never have such a tendency to fall as the inequality of its weight desires, so long as the power of the impetus that moves this body does not become less than the power of this inequality.

But when the power of the inequality exceeds the power of the impetus it makes itself the centre of the revolving motion and so this body brought to a recumbent position completes upon this centre the remainder of the aforesaid impetus.

And when the power of the inequality is equal to the power of the impetus the top is bent obliquely, and the two powers contend in a concerted movement and move one another in a great circuit until the centre of the second variety of revolving movement is established, and in this the impetus ends its power.

E 50 v.

The rows of feathers on the wings placed one above the other are set there for the purpose of strengthening the largest feathers.

Make first the anatomy of the birds, then that of their wings stripped of feathers and then with the feathers.

Parallel lines which between their extremities are equidistant from the same point are always curved, and the one is shorter than the other if they are in contact with the two sides of the same triangle.

All the feathers of the wings that grow beneath the penultimate feathers of the same wings are in process of bending during the bird's flight, and the most flexible are those which do not form a covering one to another, that is those which are pierced during the flight.

In order that a bird flying against the wind may be able to settle on

a high spot it has to fly above the spot and then turn back and without beating its wings descend upon the above-mentioned place. This is proved, for if the bird should wish to abandon its flight in order to settle, the wind would throw it backwards, and this cannot happen when it acts in the aforesaid manner.

If the flight of the bird is conditioned by the length of the bird and the wind strikes it on the side the movement of its flight must needs be between its length and the said side: as though the bird *a b* should wish to fly from *a* to *c* and the wind *f* should strike it on the flank or at the side, this bird will then direct its movement by the line *a g*, and the wind will continually bend the movement along the curve *m n c*; thus it will go where it wishes and will find itself at the spot marked *c*.

But should the wind deflect the bird's course in a more pronounced curve than its will consents to, the bird will then resume its flight against the wind as it did at first, and then with a second curving movement the wind will lead it to the desired place.

E 51 r.

Whether or no equal striking forces made with equal lengths of movement at different times will create equal lengths of movement in the objects moved: this is answered by the seventh of the ninth which says: — among moving forces of equal powers and of movements united with their objects moved, that which divides its movable thing most swiftly from itself will be that which will move this movable thing farthest from itself. At this point the adversary says that moving forces of equal power will not vary their speed and cannot therefore with similar movement drive one of two equal movable things farther from them than the other. The reply to this is that there are two kinds of moving forces of which one is sensitive and the other is not: that which is sensitive has life, and the other is without life. But that which has life moves its movable things by means of the expansion and contraction of the muscles that form parts of its limbs, this expansion and contraction being made with a greater or less amount of speed with the same power, the cause that is swiftest not being the most powerful.

No other difference is found except that the greater or less speed compresses more or less the air through which the arm of the moving force is exerted. But the insensitive moving force such as catapults or mangonels or other similar engines which by means of trapezes or by the force of cords or bent wood drive forth from themselves. . . .

The bird which one sees, carried on by its impetus, flying higher than the spot on which it desires to settle, spreads out its tail and lowers it; and striking the air with it in the course of its movement it bends its straight course and causes it to curve and makes it end upon the spot where it settles down.

The kite which descends to the east with a great slant with the wind in the north will have its movement bent to the south-east by this wind unless it lowers the right tip of its tail and bends its movement slightly to the north-east. This is proved thus: — let *a b c d* be the bird, moving to the east in the direction *n m*, and the north wind strikes it crosswise by the line *f n*, and would cause it to bend to the south-east if it were not that it has the right tip of the tail lowered to meet the wind, as it strikes it behind the centre of gravity over a longer space than existed in front of this centre of gravity, *and so its straight movement is not deflected.*[1]

E 52 r.

When the bird desires, with its wings extended, to make a circular movement which shall raise it to a height with the help of the wind, it lowers one of its wings and one of the tips of its tail towards the centre of the circle in which it is revolving.

And when the movement of the bird is circular in order to raise itself to a height without beating its wings it receives the wind under one of its wings over a fourth part of this circle; and in this way the wind makes itself a wedge and raises it up. It would turn it upside down if it were not that the other wing supported it and sustained it upon the air which strikes with a whirling movement underneath this wing, which is the one that was struck and pressed together beneath the other wing.

THINGS THAT FLY

The helms formed on the shoulders of the wings of birds are provided by resourceful nature as a convenient means of deflecting the direct impetus which often takes place during the headlong flight of birds, for a bird finds it much more convenient to bend by direct force one of the smallest parts of the wings than the whole of them; and this is why their feathers are made very small and very strong so that they may serve as a cover for one another and by so doing arm and fortify each other with marvellous power. And these feathers have their base in the small and

[1] Words crossed out in MS.

very thick bones, moved by the sinews which bend them over their joints and which are very great in these wings.

The movement and position of these bones on the shoulders of the wings is ordered and established in the same way as the thumb in the human hand, which being in the centre of the four sinews that surround it at the base with four equal spaces between them, produces by means of these sinews an infinite number of movements both curved and straight.

We may say the same of the rudder placed behind the movement of the ship, imitated from the tails of birds; as to which experience teaches us how much more readily this small rudder is turned during the rapid movements of great ships than the whole ship itself.

Why the inventors of ships do not place their rudders in front as is the case with the rudder placed in front of the shoulders of the wings:

This was not done with ships because the waves of the water are thrown up in the air to such a great height when smitten by the impetuous blow of the moving ship as would render the movement of the rudder very difficult from the gravity it would have acquired, and moreover it would often get broken. But since air within air has no weight but has condensation which is very useful the rudders (or helms) of the wings have a better use in a thick substance than in a thin one, the thick offering more resistance than the thin. The ship does the same in the added gravity of the water as has been said, and for this reason the rudder has been placed behind the ship where the water furrowed and cleft open by its course falls back from the dykes which have been made in the depth of the hollow created, and in its descent strikes the rudder with greater or less power as the falling water strikes it at angles greater or less; and in addition to this the volume of water pent up in the centre of the said concavity falls with impetus at the blow of the rudder as has been stated.

But at the tail of the kite there is the stroke of the air which presses with fury closing up the void which the movement of the bird leaves of itself, and this occurs on each side of the void so created.

The void which the bird leaves of itself successively as it penetrates in the air is struck on its sides by that part of the bird which most exceeds the space about its central line.

If the percussion which the sides of the bird make on the sides of the air they penetrate, with those parts that is which are at the greatest

distance from the centre line of their movement, is above the middle of its right side, then the straight movement will curve towards the right side, and if it is below the middle upon the opposite side this straight movement will then curve upon the left side; it will also do the same if struck above the middle of the left side as if struck below it on the left (right?) side and of the side above or of that below; and of the appearance of each we will speak in its place.

The tail of the bird spread out takes the same proportion of the bird's whole weight as is the proportion that the open tail bears to the other parts of the bird, the bust, neck, head and open wings, — and so much less in proportion as the centre of gravity of the whole bird is nearer the centre of the bust than of the tail.

[The air] runs after the vacuum which the bird leaves of itself as it pierces the air as much as the bird flies forward in the air which continually receives its contact. Consequently it is not the closing up of the air behind the bird that drives the bird before it but the impetus which moves the bird forward opens and drives the air, which becomes a sheath and draws the air behind it.

The bird which without moving its wings rises up by the help of the wind descends half the distance that it rises as it moves above the wind when its tail is turned to this wind. And as much more as the circle is larger.

E 52 v. and 53 r.

The bird that flies with a curving movement as it beats its wings beats the wing on the convex side of this movement more frequently and with a longer movement than it does on the concave side.

If the bird were to raise its wing above the wind on the side on which it is struck by this wind, this bird would be turned upside down, but for the fact that the opposite wing is lowered and bent underneath the percussion of the wind beyond the centre of its gravity, which percussion would immediately restore it to a position of equilibrium in the tips of its wings.

The bird which spreads its bulk out longer and thinner will have its flight less affected by the percussion of the wind as it receives the aforesaid percussion.

When the bird has arranged itself so that it receives the percussion of the wind slantwise, the extreme part of the lower wing bends considerably and assumes the shape of a foot and in this way it serves somewhat as a support to the weight of the bird.

Birds with short tails have very wide wings; by their width they take the place of the tail, and they make considerable use of the helms set on the shoulders of the wings when they wish to turn to any spot.

The bird that receives the wind full in front turns over as it rises and stretches out its neck towards the sky; and by lowering and opening its tail it stops itself from turning over. And this proceeds from the fact that a greater volume of wind strikes the bird below its centre of gravity than above it.

E 53 v.

In order to give the true science of the movement of the birds in the air it is necessary first to give the science of the winds, and this we shall prove by means of the movements of the water. This science is in itself capable of being received by the senses: it will serve as a ladder to arrive at the perception of flying things in the air and the wind.

Wind

The wind in passing the summits of mountains becomes swift and dense and as it flows beyond the mountains it becomes thin and slow, like water that issues forth from a narrow channel into the wide sea.

When the bird passes from a slow to a swift current of the wind it lets itself be carried by this wind until such time as it has devised a new assistance for itself, as is proved in this book.

When the bird moves with impetus against the wind it makes long quick beats of its wings with a slanting movement, and after thus beating its wings it remains for a time with all its members contracted and low.

The bird will be overturned by the wind when in a less slanting position it so arranges itself as to receive beneath it the percussion of any lateral wind.

But if the bird that is struck laterally by the wind is on the point of being overturned by this wind it will fold its upper wing, and so immediately go back to the position of having its body turned towards the ground, but if it fold its lower wing it will be immediately turned upside down by the wind.

E 54 r.

OF THE BIRD'S MOVEMENT

Of whether birds when continually descending without beating their wings will proceed a greater distance in one sustained curve, or by frequently making some reflex movement; and whether when they wish

to pass in flight from one spot to another they will go more quickly by making impetuous headlong movements, and then rising up with reflex movement, and again making a fresh descent, and so continuing: to speak of this subject you must needs in the first book explain the nature of the resistance of the air, in the second the anatomy of the bird and of its wings, in the third the method of working of the wings in their various movements, in the fourth the power of the wings and of the tail, at such time as the wings are not being moved and the wind is favourable, to serve as a guide in different movements.

Dissect the bat, study it carefully, and on this model construct the machine.

OF SWIMMING AND FLIGHT

When two forces strike against each other it is always the swiftest which leaps backwards. So it is with the hand of the swimmer when it strikes and presses upon the water and makes his body glide away with a contrary movement; so it is also with the wing of the bird in the air.

F 41 V.

Before you write about creatures which can fly make a book about the insensible things which descend in the air without the wind and another [on those] which descend with the wind.

When the bird is moving to the east with the wind in the north and finds itself with its left wing above the said wind it will be turned over, unless at the onset of this wind it puts its left wing under the wind and by some such movement throws itself towards the north-east and under the wind.

F 53 V.

AIR

Its onset is much more rapid than that of water, for the occasions are many when its wave flees from the place of its creation without the water changing its position; in the likeness of the waves which in May the course of the wind makes in the cornfields, when one sees the waves running over the fields without the ears of corn changing their place.

When the heavy substance descends in the air, and this air moves in a contrary direction in order to fill up continuously the space left by this heavy substance, the movement of this air is a curve, because when it desires to rise by the shortest line it is prevented by the heavy substance which descends upon it, and so of necessity it is obliged to bend and then to return above this heavy substance and fill up the vacuum that has been left by it. And if it were thus the air would not be compressed

beneath the speed of the heavy substance, and this being so the birds would not be able to support themselves upon the air that is struck by them; but it is necessary to say here that the air is compressed beneath that which strikes it and it becomes rarefied above in order to fill up the void left by that which has struck it. F 87 V.

BIRDS IN SLANTING MOVEMENT

The adversary says that if the bird is struck below by the wind this bird will always rise up, and this will not fail to be the case if the bird be flying against the wind. But if the bird and the wind go with equal movement along the same path it must needs be that at every degree of movement made by the wind the bird acquires a degree of descent; we may therefore say that in such time as the wind moves a degree in a horizontal position, a degree to which we may apply a name . . .

The bird that flies in an easterly direction without beating its wings as it crosses the course of the south wind gathers in its right wing and extends its left; and this inequality of wings is according to the ninth of the first which says: the birds that support themselves without beating their wings in the course of the wind, or descend through the motionless air bend their straight movement towards the side where one of the wings is pressed together.

Therefore the bird *p* flying along the line *a f* with an equal expansion of wings *n b* will bend this movement from *c f* towards *d*, gathering in the right wing from *m* to *n*. G 41 V.

The adversary says that if the movement of the bird be slanting in the course of the wind and made in a position of equality, this bird will be struck by the wind on the side underneath; and the bird which is struck underneath continually rises upward.

Birds always fly low when the course of the wind is contrary to their path, and this teaches us how the wind is more powerful at a height than low down. Here the adversary says that the wind which strikes the earth suddenly acquires more density than it had at first, and consequently it becomes more powerful and heavier.

When the bird is driven by the wind it proceeds to lower itself continually with a slanting movement; and when it wishes to raise itself again to its former altitude, it turns back with the speed of the impetus it has acquired; and this is consumed against the wind which acts as a

wedge and raises it to a greater altitude than it left; from thence it afterwards descends with the slant mentioned before, after which it acts as we said above, and so continually acquiring degrees of altitude it raises itself at last to the spot that it desires.

G 42 r.

The bird which without beating its wings descends with a great slant beneath the approach of the wind bends its straight course towards the side where one of its wings is contracted.

G 49 v.

OF THE END OF THE FLIGHT OF BIRDS

The end of the flight of birds in certain species is made with a straight and slanting movement and in others it is made with a curved slanting movement. But in the case of that which is made with a straight slant it is necessary that this movement should slant very considerably, that is that the slant is almost horizontal as is shown in *m n* [diagram].

And if the movement of these birds drops very much then of necessity this is intermingled with many reflections, and especially toward the end as will be shown in its place.

OF THE END OF THE FLIGHT THAT IS MADE UPWARDS FROM BELOW

When it is near the end [of its flight] the bird makes itself slant only a little in its length, and opens its wings and its tail very widely, but the wings reach this end with frequent tiny beats in the course of which the impetus is consumed, and so as they contract it remains for a very brief space above the spot where it finally settles with a very slight percussion of its feet.

Bats when they fly have of necessity their wings covered completely with a membrane, because the creatures of the night on which they feed seek to escape by means of confused revolutions and this confusion is enhanced by their various twists and turns. As to the bats it is necessary sometimes that they follow their prey upside down, sometimes in a slanting position, and so in various different ways, which they could not do without causing their own destruction if their wings were of feathers that let the air pass through them.

G 63 v.

OF THE COMMENCEMENT OF BIRDS' FLIGHT

When birds wish to commence their flight it is necessary for them to do so in one of two ways, one of which commences by lowering themselves with their body to the ground and then making a leap in the air by extending very rapidly their folded legs.

At the close of this leap the wings have completed their extension and the bird immediately lowers them swiftly towards the ground and reascends the second stage which is slanting like the first; and thus continuing in succession it rises to whatsoever height it pleases. Some others first raise their wings to slant forward and lower themselves as far as they can with their breasts on the ground, and in this position they extend their legs very rapidly leaping up and slanting forward, and then at the end of the effort they drop their wings so that they are slanting downwards and backwards. Thus they find themselves considerably above and in front of the place from which they set out and at the end of the effort they are in another; and so their movement continues.

There are other birds which after having lowered themselves to the ground and having their wings extended high and forwards, lower the wings and extend the legs at the same time, and thus the power produced by the first beating of the wings allied to the power acquired by extending the legs becomes very great, and this power united is the greatest that it is possible to create for the beginnings of the flights of these birds.

The second method employed by birds at the commencement of their flight is when they are descending from a height: they merely throw themselves forward and at the same time spread their wings high and forwards and then in the course of the leap lower their wings downwards and backwards, and so using them as oars continue their slanting descent.

Others have the habit of throwing themselves forward with wings closed and then opening the wings as they descend, and having opened them are stopped by the resistance of the air, and then close them and fall again.

G 64 r.

THE FLIGHT OF THE FOURTH SPECIES OF BUTTERFLIES THE DEVOURERS OF THE WINGED ANTS

The butterflies with four equal and separated wings (ant lions) always fly with the tail high using it as a rudder for any sort of movement. That is that if one of these insects wishes to descend it

lowers its tail and if it wishes to ascend it raises its tail, and if it wishes to turn to the right or left it bends its tail to the right or left and the same with all sorts of angles of movement which lie between the said four principal movements. And this is the largest butterfly of the aforesaid species, black and yellow in colour.

It uses its four wings in short wheeling flights when it wishes to prey on the small winged ants, moving sometimes the right forward and the left backward and sometimes the left forward and the right backward because the rudder formed by the tail is not sufficient to regulate the speed of its movement.

OF THE THREE CHIEF POSITIONS WHICH THE WINGS OF BIRDS ASSUME AS THEY DESCEND

Of the three chief positions which the wings of birds assume as they descend slantwise without beating their wings, the first is *a b c* in which the wings have their extremities of equal height and so also the opposite angles of the tail, whence their movement will descend by the slant *a d*. The second arrangement will be *a e f*, in which the extremities of the wings and the angles of the tail are of different heights, the left wing being higher, and its slanting movement being *a g*. The third arrangement of the slant of the same wings is the converse of the second, for in it the left wing is lower than the right; and its movement is at *a o*, and the position of the wings is *n m*. G 64 v.

A SCREEN TO PREVENT THE WIND FROM TURNING THE BIRD UPSIDE DOWN

I have seen the bird turned upside down by the wind on its left when it entered above the wind with its left wing.

In the case of all the birds that fly high as they raise their wings they remain perforated, as is shown in its place. And as the wings descend they remain united; so as the compressed and condensed air does not yield place to the descent of the wings with the same speed as the wing, it becomes necessary for the bird to have the reflex of such percussion, by which it rises and is carried to a height, by the impetus acquired, through as great a span of height as the impetus of the reflex has of life. And in this time the wings reopen and become perforated with the spaces interposed between the said feathers, then the bird lowers its wings again violently as it closes up its feathers, and so acquires anew the impetus

that it had lost. And in this way all the birds act which rise in straight movement such as the lark and the like. And those birds which do not possess such a wide expanse of feathers such as birds of prey, it is necessary for them to raise themselves by turning round, that is in the form of a screw or otherwise in circular movement.

The butterfly and many similar insects all fly with four wings having those behind smaller than those in front. Those in front form a partial covering to those behind, and all the insects of this class possess the power to rise with straight movement, for as they raise themselves on these wings they remain perforated because they keep the front wings much higher than those behind. And this continues almost to the end of that impulse which urges them upwards, and then as they lower their wings the larger become joined to the lesser, and so as they descend they again acquire a fresh impulse.

There are also other kinds of flying insects which fly with four wings equal, but these do not cover each other in their descent any more than in their rise; and those of this kind cannot rise with straight movement.

G 65 r.

OF PERCUSSION—FLIGHT OF MAN

Of the things that fall in the air from the same height, that will produce less percussion which descends by the longer route: it follows that that which descends by the shorter route will produce more percussion.

This first movable thing formed of paper slightly curved has its first descent with the front *b* and moves from *a* to *c*, in which movement *a* descends farther than *b*; consequently *a* at the end of the reflex movement finds itself at *c*, and *b* is raised to *d*. And this is proved by the ninth of this which says:—the thing that strikes the air with a greater part of itself has less power to penetrate this air. And by the tenth:—that thing is swifter in penetrating the air which strikes it with less breadth. And by the eleventh:—the heaviest part of a body that moves through the air becomes the guide of the movement of this body.

This may be proved:—let *a b* be the heavy substance, which, although in itself of uniform thickness and weight, being in a slanting position, has a front that has more weight than any other part of its breadth

equal to the front which can serve as its face, and for this reason the front will become the guide of this descent. And by the twelfth: — that air offers most resistance to its moving thing which is most compressed; therefore that face weighs least with its parts which has below it the compressed air. And by the thirteenth: — the air that has the swiftest movement moves most — it follows that the man can descend as is shown below.

This [man] will move on the right side if he bends the right arm and extends the left arm; and he will then move from right to left by changing the position of the arms.

G 74 r.

GRAVITY

Every slanting movement made by a heavy substance through the air divides the gravity of the movable thing in two different aspects, one of which is directed to the place towards which it moves and the other to the cause that restrains it.

G 74 v.

[*Of the wings of the fly*]

The lower wings are more slanting than those above, both as to length and as to breadth.

The fly when it hovers in the air upon its wings beats its wings with great speed and din, raising them from the horizontal position up as high as the wing is long. And as it raises them it brings them forward in a slanting position in such a way as almost to strike the air edgewise; and as it lowers them it strikes the air and so would rise somewhat if it were not that the creature threw its weight in the opposite direction by means of its slant. As though the slant of the fly when stationary in the air was along the line *e f*, and the slant of the movement of the wings between the straight up and the straight down position followed the lines *a b*, *c d* which intersect with the line of the descent *e f* between right angles, in such movement that the power of the descent by the slant *e f* is equal to the power that it has to raise itself by the slant of the movement of the wings by the slant *d b c a*.

And the back legs serve it as a rudder, and when it wishes to fly it lowers its wings as much as possible.

G 92 r.

The ascent[1] of birds or their rebound near to any object will never extend as far as the descent or will not exceed it.

H 33 v.

The bird rises to a height in a straight line without beating its wings when the reflex movement of the wind strikes it from underneath.

I have divided the Treatise on Birds into four books; of which the first treats of their flight by beating their wings; the second of flight without beating the wings and with the help of the wind; the third of flight in general, such as that of birds, bats, fishes, animals and insects; the last of the mechanism of this movement.

K 3 r.

If one of the wings is lowered rapidly and then folded, the bird drops a little on that side; and if it is lowered rapidly and extended the bird drops on the opposite side; and if it is lowered slowly and extended the bird moves in a circle round this wing, falling as it proceeds; and if it is lowered slowly and with hesitation and folded up the bird then descends in curves on that side.

K 4 r. and 3 v.

All birds driven by the water or by the wind keep their heads in the direction from whence the water or the wind is coming. They do this in order to prevent the wind or the water penetrating up from the extremities to the roots of the feathers, so that each of the feathers may be pressed against one another, and thus they may remain drier and warmer.

K 3 v.

When the bird lowers one of its wings necessity constrains it instantly to extend it, for if it did not do so it would turn right over. The bird when it wishes to turn does not beat its wings with equal movement, but moves the one which makes the convex of the circle it describes more than that which makes the concave of the circle.

K 4 v.

If the rudder or tail of the bird is beneath the wind the bird will be pulled down by the wind from its middle backwards, and turned with its front towards the wind.

And if the bird is struck on the slant of its tail above the wind it will be pulled down in front and turn towards the wind.

K 5 r.

[1] MS. calare.

The bird often beats twice with one wing and once with the other and it does this when it has got too far over to that side.

It also does the same when it wishes to turn on one side; it takes two strokes with one wing backwards, keeping the opposite wing almost stationary pointing towards the spot to which it ought to turn.

K 5 V.

The helms of the wings are used when the bird is struck from behind by the wind and rests slantwise upon the air that supports it: the bird is then struck by the wind in the front of these helms and so is driven upwards, its reflex movement being increased by the movement of the wind.

K 6 r.

If the extent of the slant of the tail from the centre of the bird backwards is more than that of the wing from the centre of the bird forwards the bird will turn to face the wind. But if the slanting part of the wing is greater in extent than that of the tail then the tail will turn towards the approach of the wind.

K 6 v.

The bird beats its wings repeatedly on one side only when it wishes to turn round while one wing is held stationary; and this it does by taking a stroke with the wing in the direction of the tail, like a man rowing in a boat with two oars, who takes many strokes on that side from which he wishes to escape, and keeps the other oar fixed.

K 7 r.

Of the flexion of the tip of the wing even when the wing does not beat.

The helms which are on the shoulders of the wings are necessary when the bird in its flight without beating its wings wishes to maintain itself in part of a tract of air, upon which it is either slipping down or rising, and when it wishes to bend either upwards or downwards or to right or left. It then uses these helms in this manner:— if the bird wishes to rise it spreads the helm in the opposite direction to the way the wind strikes it; and if to descend it spreads the top part of the helm slanting to the course of the wind. If it turns to the right it spreads the right helm to the wind, and if it turns to the left it spreads the left helm to the wind.

K 7 V.

The helm of the wing is used by the bird when in flying it supports

itself upon its wings raised so that by their vibration they prevent it from descending; and in addition to this these helms or fingers show themselves fronting the air down which the slant of the bird is gliding, and by thus striking upon it with these helms it resists it as it glides.

That bird descends most rapidly which has the least distance between the extremities of the tips of its wings. K 8 r.

The birds which seek to penetrate within the approaching wind are in the habit of fluttering to the right and to the left, like sailors tacking against the direction of the winds; and this they do in order not to make a long descent, for if the bird did not guard against descending for any great distance, it would be driven right against the current of the wind; and, entering under the wind slanting lengthwise, it will present so much of its weight by this line as to subdue the resistance of the wind. K 8 v.

The 'hands' of the bird show themselves in front, close to the spot where it descends by a straight slant in order to consume the impetus it has acquired.

By beating its wings in order to support itself at a height and to advance from the 'hand' behind, it supports itself at the height and the 'hand' causes it to make progress. K 9 r.

When the bird is carried along by the wind and wishes to turn quickly towards it, it will then enter beneath the wind with the wing turned towards it; and then with the feathers of the tail turned towards the wind, it will enter upon it, and so by the help of the wind striking upon its tail it turns much more rapidly. K 9 v.

The wing bends so much the more in proportion as the bird is swifter in the same space of time.

What difference there is between the tips of the wings of birds which bend and those which do not, and whether to bend up and down thus is necessary for the flight of these birds or no, since one sees that however slightly these tips are cut the bird's power of flight is almost stopped. K 10 r.

When the bird rises up by the assistance of the wind without beating its wings, it spreads out and raises its wings so that they form an arch with the concave side towards the sky, and it receives the wind under

its wings continually, in its movement to and fro, and this would cause it to turn right over if it were not that the point of its tail is turned to the wind as it enters beneath the wind; and this afterwards by its power of resistance acts to prevent the said movement of turning over, because the wings are restrained by the tail in such a way that their various parts are of equal power, and so the tail becomes partly lowered and the bird is raised forward slightly.

K 10 V.

Always the wind that strikes the tail is farther removed from the centre and more powerful than that of the wing.

What has been set forth before is here proved. I say that if the wing be in such a position in relation to the tail that the amount of the wind *a b* which strikes the wing *m o* is equal to the amount of the wind *b c* which strikes the tail above at *o n*, the bird will not turn, but will be carried in the line of the course of the wind. But if the wind that strikes the tail above is more powerful than the wind that strikes beneath the wing, then the tail will move away and will be dominated by the power of the wind, and the wing will turn to the wind which will be more powerful than it was before, because the movement that the wing makes against the wind increases in speed and power, and so the wind entering beneath it forms a wedge there and raises and turns it.

K 11 r.

When the bird wishes to ascend it drives the centre of its gravity behind the centre of its wings, and it does this in order to be in a slanting position. It is of the nature of an equable wind to straighten all the uneven parts of the bird, placing it with its extremities equidistant from the centre of its bulk, this being understood of such as support themselves without beating their wings in the air by the help of the wind; and consequently it makes first a circling movement and then a straight movement.

K 11 V.

When the bird wishes to avoid being turned over by the wind it has two expedients, one of which is to move the wing that was above the wind and place it suddenly below the wind, that is to say the one that was turned to the wind; the other is to lower the opposite wing so that the wind that strikes it on the inside is more powerful than on the wing that faces the wind.

K 12 r.

The bird in its flight without the help of the wind drops half the wing downwards, and thrusts the other half towards the tip backwards; and the part which is moved down prevents the descent of the bird, and that which goes backward drives the bird forward.

When the bird raises its wings it brings their extremities near together; and while lowering them it spreads them farther apart during the first part of the movement, but after this middle stage as they continue to descend it brings them together again.

K 12 V.

The point of the wing of the bird serves to guide it through the air as the point of the oar does through the water or the arm or hand of the swimmer beneath the water. But here arises a doubt as to whether, if for instance the bird be travelling along the line *f a* and the wing or rather the point move backward moving from *a* to *f*, it makes its path by *a b f*, driving the bird forward, and returns towards *a* by the path above *f c a*, or whether it really acts as the hand of the swimmer does under the water which forces itself back by the line above *a c f* and returns by *f b a*.

K 13 r.

When the bird is borne along by the help of the north wind, and moves with it to the south, it keeps one wing fixed to the north-east, a little above the wind, and lowers the wing that is to the south-west and makes it serve as a cover to the wind by receiving there beneath it the percussion of the wind slantwise. It seldom beats this wing but it is entirely by means of it that it maintains its equilibrium, whether the wind be greater or less.

When the bird ascends by reflex movement against the wind, if it did not turn round on its lower wing it would by this reflex movement turn back with its breast to the wind, and this wind would overthrow it.

And ascending by reflex movement with its spine to the wind it would turn back with its spine below the wind.

K 13 V.

The thrushes and the other birds fly readily against the wind.

When the bird wishes to let itself fall on one of its sides it throws its wing down rapidly on the side on which it wishes to descend, and the impetus of this movement causes the bird to drop on this side.

When the north wind blows and the bird is carried by the wind and

wishes to return facing the wind, it drives the wing downwards and turns and enters with its spine beneath the wind.

K 14 r.

A bird beats its wings frequently as it settles when it has descended from a height, in order to break the impetus of the descent, to settle itself on the ground and to diminish the force of the impact.

K 58 [9] r.

When birds ascend by wheeling round with the wind they keep their wings very high so that the wedge of the wind and of the impetus may raise them.

When they move in a downward direction they lower their wings for two reasons; the first is because less air sustains them, the other because the wind serves as a wedge above them and drives them down and continually lowers them.

K 58 [9] v.

Many are the times when the bird beats the corners of its tail in order to steer itself, and in this action the wings are used sometimes very little, sometimes not at all.

K 59 [10] r.

When the kite rises or sinks without beating its wings, it holds them slanting, and keeps the tail slanting in the same way but not to the same extent, for if this were so the bird would fall to the ground by the line of the slant of the wings and of the tail; but as this tail is away from the centre of the bird's length it meets with somewhat more resistance than the wings, and this in consequence checks its movement, and so the tail has less movement than the wings. Necessity causes the bird to move with a circular motion, and as the tail is less slanting so in proportion the circles are less in diameter, and so also conversely.

K 59 [10] v. and 60 [11] r.

When the bird flies along a level line it seems that the nearer it approaches the eye the more it rises.

[*Diagram*]

Let *g h* be the level line and let the bird be moving along *g c s*, and let *n* be the eye. I say that as the images of the bird rise in every stage of its movement in every stage of height in the pupil it seems to the eye that this bird is rising.

K 121 [41] v.

And if the bird flies along a level line separating itself from the

eye it will seem to be descending stage by stage with the stages of its movement.

K 121 [41] r.

The slanting movement made by the descent of birds commences with the wings straight and low. Gradually they stretch out their wings in order to consume the access of impetus which heavy bodies acquire at each stage of their descent. And when such a movement is retarded by the too great expansion of wings then this bird again contracts its wings and so again the descent commences to become swift.

[*Drawing*]

Route made through the air by flying things which descend, with their expansion and contraction of wings.

L 54 r.

[*Slanting flight of birds*]

When the bird descends by any slant whatever it brings the humerus of the wings near to its shoulders and draws together the points of the wings towards the tail, and this tail is also drawn together into itself and by so doing it meets with a less volume of air to resist its descent.

But when this bird wishes to turn to the right or to the left it will extend its right or left wing, that is to say the wing that is on the side on which it wishes to turn. This extended wing finds a greater volume of air and in consequence comes to meet with a greater resistance, with result that it slackens its pace more than the opposite wing does which is more contracted, and as the one wing moves more than the other the bird transforms its straight movement into a circling movement; but if the wing which is more contracted towards the bird's body than the other cannot expand with that ease which the bird requires, then it spreads out its tail and twists it thus open towards the side where this wing is contracted. This bird will then fly in a straight movement and so as you see it will leave the circular movement.

There are two helms on the humerus of the wings of each bird, and these without making any change of wings have power to cause the birds various movements between ascending and descending; it is only in the transversal movements that the helm of the tail takes part.

L 54 v. and 55 r.

[*The flight of birds with the wind*]

The movement of things that fly is much swifter than that of the wind. For if it were not so no bird would move against the wind. But

its movement against the wind is as much less than its natural course within the still air as the degrees of movement of the wind are less than that of the bird.

Let us say the bird moves in the still air at a speed of six degrees and the wind of itself moves at a speed of two degrees, then this wind following its natural course takes away two degrees of speed from this bird and consequently of the six degrees there remain four.

But if such bird were to fly at six degrees of speed together with the course of the wind which imparts to it its two degrees, this bird would be flying at eight degrees of speed. Here however one should observe how the wing is supported in its percussion in the motionless air, the retreating air or the air that follows after it, and guide one's self according to these rules.

L 55 v.

[*Flight of birds — the lark*]

When the bird finds itself upside down, as is seen at *a*, the tips of the wings are driven towards the ground as is shown at *b*; and then this flying thing will straighten itself in its first position, but it bends the tail spread out towards its spine.

And if it falls edgewise it will raise its wings towards its spine and then straighten itself.

There are many varieties of birds which can only raise themselves spirally, that is by revolving movements; the lark is an exception because as it raises its wings it proceeds to transpierce them with air in such a way that they offer no resistance being almost entirely transpierced.

When the bird wishes to go down it throws its wings backward in such a way that the centre of their gravity comes away from the middle of the resistance of the wings and so it comes to fall forward.

L 56 r.

The flight of many birds is swifter than is the wind which drives them. And this arises from driving the wings in the wind which carries this bird. If it were not so the birds that rest upon the wind would not be able to fly against the wind.

The bird in raising its wings sends them partly forward and partly upward, and the whole wing comes to go edgewise, and each feather of itself, and in addition to this it remains transpierced; and as it proceeds downward it thrusts it back in face of the air or of the wind

and the transpiercing of the feathers and of the whole wing become united.

L 56 v.

[*With drawings*]

The manner of resistance of the feathers as the bird drops down.

The resisting *a b* as it is flexible is bent by the line of any movement of air, and there will be the same result with paper protected as with ribs by the stems of the reeds.

L 57 r.

[*Wings of birds*]

The bird which is swifter in lowering than in raising its wings is that which raises itself more by pressing the underpart of the wings towards the centre of the earth.

But if they press this underpart of the wings towards the horizon they will make equal movements.

[*Drawing*]

You will note if the feathers of *c a* are placed above in the manner and order of *a b*.

A b n m is the position of the shutters (sportelli).

L 58 r.

The opening and lowering of the tail and the spreading out of the wings at the same time to their full extent, arrests the swift movement of birds.

When birds in descending are near to the ground, and the head is below the tail, they then lower the tail, which is spread wide open, and take short strokes with the wings; and consequently the head becomes higher than the tail, and the speed is checked to such an extent that the bird alights on the ground without any shock.

In all the changes which birds make in their lines of movement they spread out their tails.

There are many birds which move their wings as swiftly when they raise them as when they let them fall: such as magpies and birds like these.

L 58 v.

There are some birds which are in the habit of moving their wings more swiftly when they lower them than when they raise them, and this is seen to be the case with doves and such like birds.

There are others which lower their wings more slowly than they raise them, and this is seen with rooks and other birds like these.

The birds which fly swiftly, keeping at the same distance above the ground, are in the habit of beating their wings downwards and behind them, downwards to the extent necessary to prevent the bird from descending, and behind when they wish to advance with greater speed.

The speed of birds is checked by the opening and spreading out of the tail.

L 59 v.

When the slant of the flying thing is struck by the wind in its lower part this flying thing will rise upwards.

But when this slant is struck in its upper part this flying thing will be constrained to descend from its height.

But if the wind which strikes the said birds in the part below were to overturn them the flying thing will then contract its wings somewhat, with result that it will descend by its heaviest part.

L 60 r.

When the kite in descending turns itself right over and pierces the air head downwards, it is forced to bend the tail as far as it can in the opposite direction to that which it desires to follow; and then again bending the tail swiftly, according to the direction in which it wishes to turn, the change in the bird's course corresponds to the turn of the tail, like the rudder of a ship which when turned turns the ship, but in the opposite direction.

When the wind is about to throw the bird backward the bird draws together the shoulders of its wings, so that its weight is massed more to the front than it was at first, and consequently the part that is heaviest is first in its descent, while in addition the tail is spread out and bent down.

L 62 r.

[*Tail and wings of birds*]

When one of the sides of the tail of the flying body is lowered with a swift movement, then the air where it strikes is more compressed and as a consequence offers more resistance, whence of necessity the bird bends with its opposite side, and so the movement of this bird is curved circling round the part of the tail which is lower.

But when it is sometimes the one and sometimes the other point of the tail which impels it to lower itself sometimes to the right and sometimes to the left, it does not make a circling movement but it is merely a way of striking the air as wings would do. When this bird feels itself

dropping on one of the sides this tail beats the air on the opposite side and in this way it resists this tendency.

L 62 V.

[*A goose swimming and flight*]

OF MOVEMENT

Swimming illustrates the method of flying and shows that the weight which is largest finds most resistance in the air. Observe a goose's foot: if it was always open or closed in the same manner the creature would not be able to make any kind of movement. It is true that the curve of the foot outwards would have more perception of the water in going forward than the foot would have as it was drawn back; this shows that with the same weight the wider it is the slower its movement becomes.

Observe the goose moving through the water, how as it moves its foot forward it closes it and covers but little water and consequently acquires speed, and as it draws it back it spreads it out and so makes itself slower, and then the part that has contact with the air becomes swifter.

M 83 r.

When one wing bends with the same speed as the other but with a longer movement it will cause the straight movement to bend to a curve.

B.M. 43 r.

CONCERNING THINGS THAT CAN FLY

In the case of every heavy thing descending freely the heaviest part will become the guide of its movement.

B.M. 96 r.

[*Drawing — bird with wings extended*]

This raises itself in circles by means of the wind. This creature is always struck below by the wind by a slanting line; and when this wind strikes it in front it bends its wings with its shoulders towards the sky; and when the wind catches it in the tail it bends its shoulders towards the ground. And so always this bird takes the wind at its centre of gravity in front or behind or at the side.

B.M. 134 r.

The tail adds or takes away the weight from the wings of the bird.

Every heavy substance moves by the line where it has least resistance.

The heavy substance finds least resistance by the line in which it weighs most.

B.M. 146 r.

That bird will raise itself in flight more readily which gets the impetus of its movement by dropping somewhat at the beginning of its flight.

When a bird flies against the wind it is necessary that the progress which it makes against the wind should be made in a slanting line towards the earth, entering underneath the wind. And this because its weight is more powerful than that of the amount of wind which strikes it at unequal angles, and would wish to press it down towards the ground if it were not that the air which is in front in the line of its movement is far less in amount than the air which happens to be below it and which touches it. This movement alone suffices to subdue that air which offers less resistance, and that will offer less resistance which is less in quantity.

Therefore from what has been stated we are certain that the bird will move itself against that part of the air which offers less resistance and which meets the helms of the wings, rather than against that which meets it from below along the whole extent of these wings.

Rectilinear movement

But when this bird wishes to rise to a height it will enter above the wind, and it will retain enough of the impetus it has acquired in the descent we have spoken of, so that by means of the speed thus gained it will lower its tail and likewise the elbows of its wings and will raise up its helms. It will then be above the wind, and as this impetus is constrained neither to cease nor to be consumed its nature forthwith compels it to follow along the line where the least amount of air impedes its movement, which will be in that line in which the wings show themselves edgewise to the air where they strike, that is along the line where the air as it is met is always divided by the helms which are in the thickness of the wings and never along the line of their width.

After having done this then the bird rises up without beating its wings, for the wind which passes underneath it raises it up as a wedge raises a weight, and for this reason would cause it to turn backwards, if it were not that in this act of rising it is continually becoming slower and consuming the impetus already acquired. And after this impulse has been consumed the bird would be overturned by the wind which has carried it up to a height if it did not immediately lower the helms of the shoulders of the wings, enter underneath the wind and lower its tail. Then the movement which has just ended commences anew, and as it

drops it acquires again the impetus which it has lost, with which it again rises up to a height with reflex movement until it again loses the impetus that it has acquired.

If however such movement were circular then the bird would follow other rules which will subsequently be defined in due order. B.M. 166 v.

OF THE BIRD THAT MOVES WITHOUT WIND OR BEATING OF WINGS

The movement of a bird without beating of wings or help of wind is along a line that slants steeply downwards and then rises with a reflex movement. By this reflex movement it raises itself seven eighths of the height of its falling movement and it goes on doing this little by little until it reaches the ground.

OF THE MOVEMENT AGAINST THE WIND WITHOUT BEATING OF WINGS WHICH RAISES THE BIRD

Here the falling movement is below the wind and the reflex movement will be above the wind. B.M. 277 r.

[*Diagram wing* $\begin{matrix} b\,d\,f \\ a\,c\,e \end{matrix}$ *g*]

I find in the wings of birds three causes of power, of which the first is *b* which derives its strength from the muscle *a*; the second may be *d c*; the third may be *f e*; now I ask: if the part *g* produces its force by means of *f e* what force penetrates to *b a*, or to put it more exactly what weight? Forster II 34 v.

The reflex movement made by the bird against the course of the wind becomes considerably greater than its falling movement; and it is the same with the succeeding reflex movement because it is driven by the same course of the wind. Quaderni II, 16 r.

XVIII

Flying Machine

'I find that if this instrument made with a screw be well made— that is to say, made of linen of which the pores are stopped up with starch—and be turned swiftly, the said screw will make its spiral in the air and it will rise high.'

The man in the bird rests on an axis a little higher than his centre of gravity.

C.A. 129 V. a

A bird is an instrument working according to mathematical law, which instrument it is within the capacity of man to reproduce with all its movements, but not with a corresponding degree of strength, though it is deficient only in the power of maintaining equilibrium. We may therefore say that such an instrument constructed by man is lacking in nothing except the life of the bird, and this life must needs be supplied from that of man.

The life which resides in the bird's members will without doubt better conform to their needs than will that of man which is separated from them, and especially in the almost imperceptible movements which preserve equilibrium. But since we see that the bird is equipped for many obvious varieties of movements, we are able from this experience to declare that the most rudimentary of these movements will be capable of being comprehended by man's understanding; and that he will to a great extent be able to provide against the destruction of that instrument of which he has himself become the living principle and the propeller.

C.A. 161 r. a

[*Diagrams of mechanism of flying machine*]

I conclude that the upright position is more useful than face downwards, because the instrument cannot get overturned, and on the other hand the habit of long custom requires this.

And the raising and lowering movement will proceed from the lowering and raising of the two legs, and this is of great strength and the hands remain free; whereas if it were face downwards it would be very difficult for the legs to maintain themselves in the fastenings of the thighs.

And in resting the first impact comes upon the feet, and in rising they touch at *r S t*; and after these have been raised they support the machine, and the feet moving up and down lift these feet from the ground.

Q is fastened to the girdle; the feet rest in the stirrups *K h*; *m n* come beneath the arms behind the shoulders; *o* represents the position of the

head; the wing in order to rise and fall revolves and folds . . . the same.

C.A. 276 v. b

[*With drawings of parts of flying machine*]

Spring of horn or of steel fastened upon wood of willow encased in reed.

The impetus maintains the birds in their flying course during such time as the wings do not press the air, and they even rise upwards.

If the man weighs two hundred pounds and is at *n* and raises the wing with his block, which is a hundred and fifty pounds, when he was above the instrument, with power amounting to three hundred pounds he would raise himself with two wings.

C.A. 307 r. b

[*Drawing of wing of flying machine*]

1 Let *a* be the first movement.

2 Undo one and remove. . . .

3 Double canes . . . soaped. . . .

4 of rag or [skin] of flying fish.

5 Spring with lock *n o* is a wire that holds the spring, and it is not straight. Spring of wing.

6 The spring *b* should be strong, and the spring *a* feeble and bendable, so that it may easily be made to meet the spring *b*, and between *a b* let there be a small piece of leather, so that it is strong, and these springs should be of ox-horn, and to make the model you will make it with quills.

7 Take instead of the spring filings of thin and tempered steel, and these filings will be of uniform thickness and length between the ties, and you will have the springs equal in strength and power of resistance if the filings in each are equal in number.

C.A. 308 r. a

[*Drawing of wing of flying machine*]

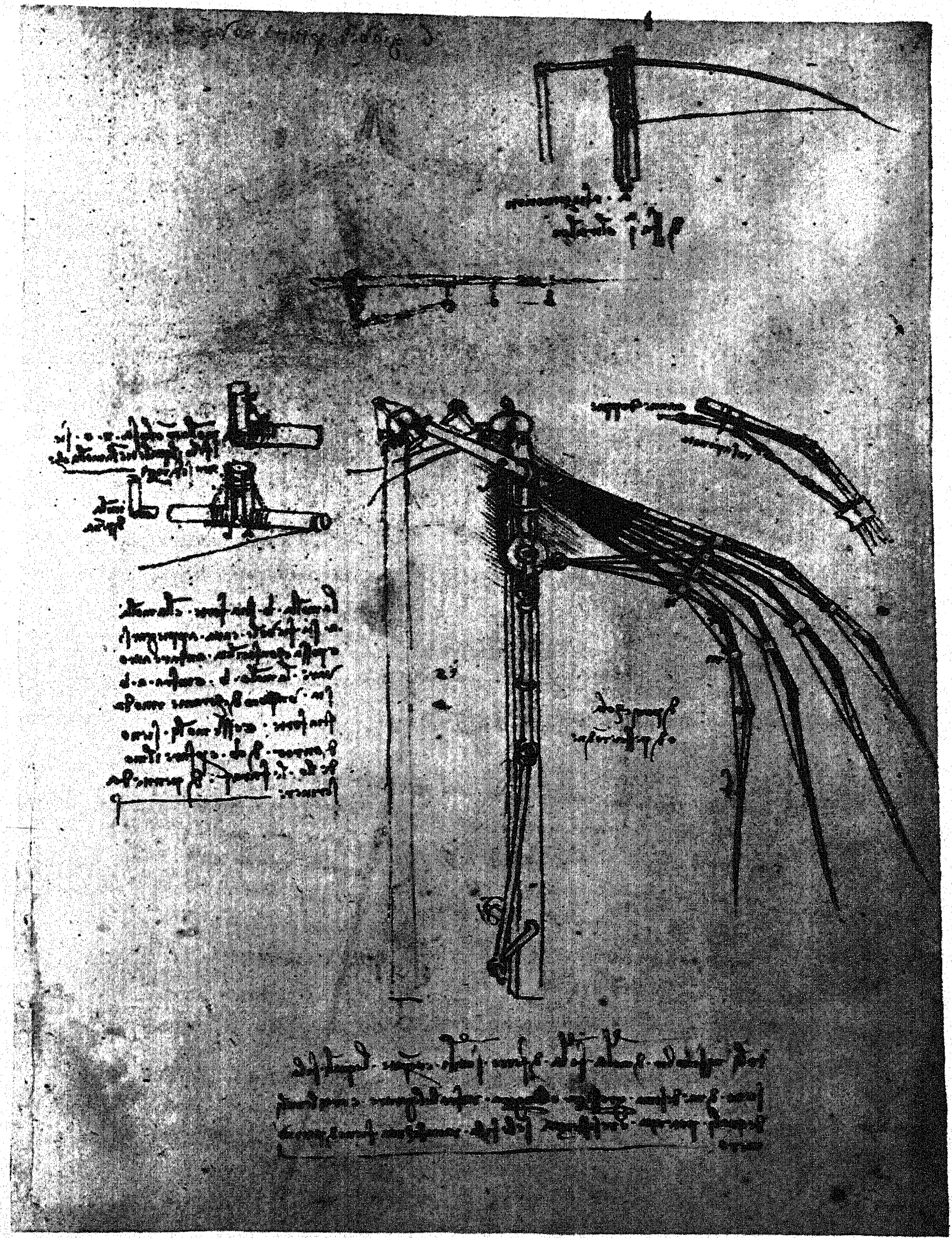
Net. Cane. Paper.

Try first with sheets from the Chancery.

Board of fir lashed in below.

Fustian. Taffeta. Thread. Paper.

C.A. 309 v. b



STUDY OF MECHANISM OF WING OF FLYING MACHINE

MS. Codice Atlantico 308 *r.a.*

[Text: I. 512]

[*Drawing of wing of flying machine*]

For Gianni Antonio di Ma[. . .]olo, (Mariolo).

Not to be made with shutters but united.[1]

C.A. 311 v. d

THE NATURE OF THE STAFF WHEN UNTIED AND ITS CORD

The cord should be of oxhide well greased, and the joints also where the play is, or they should be soaped with fine soap.

The staff should be of stout cane or it may be of various different pieces of cane, and of any length you choose since you make it in pieces. The springs should be made with bands of iron between the joints of each spring, uniform in thickness, number and length, so that they may all bend at the same time and not first one and then the other; and each spring should of itself have many of these bands of iron, of which it is made up. But if you prefer not to use bands of iron take strips of cow's horn to make these springs.

C.A. 308 v. a

[*With drawing of wing of flying machine*]

It requires less effort to raise the wing than to lower it, for as it is being raised the weight of the centre which desires to drop assists it considerably.

C.A. 317 v. a

To-morrow morning on the second day of January 1496 I will make the thong and the attempt.

[*Drawing — apparently of strip of leather stretched on frame*]

To make the paste, strong vinegar, in which dissolve fish-glue, and with this glue make the paste, and attach your leather and it will be good.[2]

C.A. 318 v. a

[*With drawing of flying machine*]

The foundation of the movement.

C.A. 314 r. b

[1] Note referring probably to the construction of a machine for flight as a commission for a patron, Gian Antonio di Mariolo, who desired that the wings should be so made that they could not be penetrated by the wind.

[2] The words (soatta) 'thong' and (corame) 'leather' seem to point to the probability that these two sentences refer to the construction and trial of the same instrument, probably a flying machine.

[*Various diagrams in which figure of man is seen exerting force with arms and legs*]

Make it so that the man is held firm above, *a b*, so that he will not be able to go up or down, and will exert his natural force with his arms and the same with his legs.

Close up with boards the large room above, and make the model large and high, and you will have space upon the roof above, and it will be more suitable in all respects than the Piazza d'Italia.

And if you stand upon the roof at the side of the tower the men at work upon the cupola will not see you.

a b produces force estimated at three hundred, and the arms at two hundred, which makes five hundred, with great speed of....

The lever one braccio and the movement a half, the counter-lever eight braccia, and for the weight of the man I will say four, so that it comes to three hundred with the instrument.[1]

C.A. 361 v. b

There is as much pressure exerted by a substance against the air as by the air against the substance.

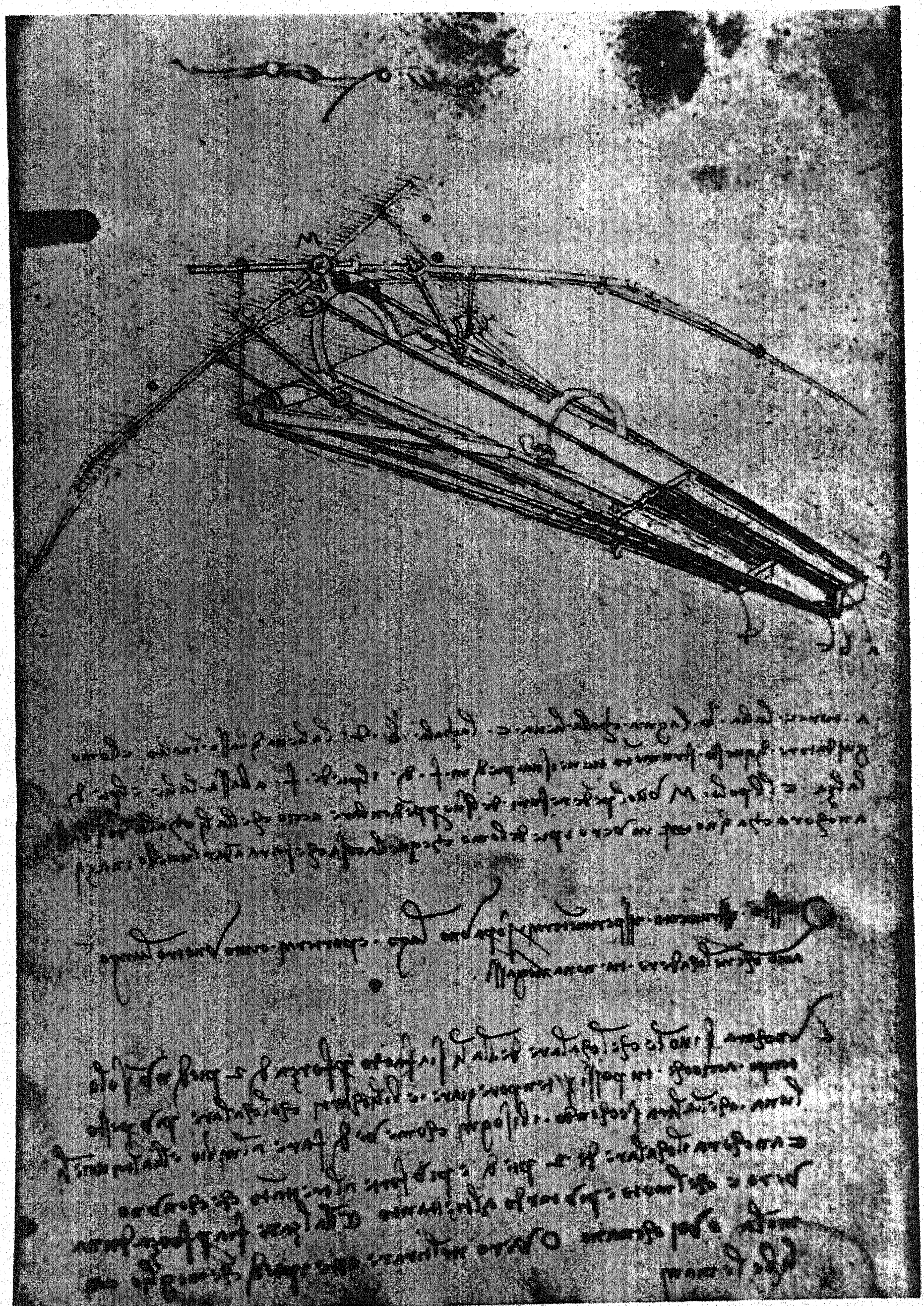
Observe how the beating of its wings against the air suffices to bear up the weight of the eagle in the highly rarefied air which borders on the fiery element! Observe also how the air moving over the sea, beaten back by the bellying sails, causes the heavily laden ship to glide onwards!

So that by adducing and expounding the reasons of these things you may be able to realise that man when he has great wings attached to him, by exerting his strength against the resistance of the air and conquering it, is enabled to subdue it and to raise himself upon it.

[*Sketch — man with parachute*]

If a man have a tent made of linen of which the apertures have all been stopped up, and it be twelve braccia across and twelve in depth,

[1] On the same page of the manuscript Leonardo has drawn a rough map of Europe with names of provinces inserted. Below this the Iberian peninsula is repeated with lists of provinces arranged under the three heads:—Spain, France and Germany. It is not perhaps entirely fantastic to suppose that these maps and lists of provinces, occurring on the same sheet as the foregoing memoranda of the construction of an instrument for flight, may have been connected in his mind with possibilities of travel that the invention of flying would open up and that the sketches were in intention aviators' maps. The reference to the roof at the side of the tower as being out of sight of the men working upon the cupola shows that the model was being made in a house not far from the Cathedral.



FLYING MACHINE

Institut de France MS. B. 74 v

[Text: I. 515]

he will be able to throw himself down from any great height without sustaining any injury.

[*With drawing of pair of balances in one of which the figure of a man is seen raising a wing*]

And if you wish to ascertain what weight will support this wing place yourself upon one side of a pair of balances and on the other place a corresponding weight so that the two scales are level in the air; then if you fasten yourself to the lever where the wing is and cut the rope which keeps it up you will see it suddenly fall; and if it required two units of time to fall of itself you will cause it to fall in one by taking hold of the lever with your hands; and you lend so much weight to the opposite arm of the balance that the two become equal in respect of that force; and whatever is the weight of the other balance so much will support the wing as it flies; and so much the more as it presses the air more vigorously.

C.A. 381 v. a

[*With drawings*]

a b c causes the part *m n* to raise itself up quickly in the rising movement, *d e f* causes *m n* to descend rapidly in the falling movement, and so the wing performs its function.

r t lowers the wing by means of the foot, that is by stretching out the legs, *v s* raises the wing by the hand and turns it.

The way to cause the wing to turn just as it rises or descends.

Device which causes the wing as it rises to be all pierced through and as it falls to be united. And this is due to the fact that as it rises *b* separates from *a* and *d* from *c* and so the air gives place to the rising of the wing, and as it falls *b* returns to *a* and similarly *c* to *d*; and the net bound to the canes above makes a good protection, but take care that your direction be from *a* to *f* so that the landing[1] does not find any obstacle.

B 73 v.

[*With drawings: section of wing*]

Device so that when the wing rises up it remains pierced through and when it falls it is all united. And in order to see this it must be looked at from below.

[1] MS. has 'lariua'.

[*Sketch of wing*]

Make the meshes of this net one eighth wide.

A should be of immature fir wood, light and possessing its bark.

B should be fustian pasted there with a feather to prevent it from coming off easily.

C should be starched taffeta, and as a test use thin pasteboard.

B 74 r.

With drawing of flying machine

a twists the wing, *b* turns it with a lever, *c* lowers it, *d* raises it up, and the man who controls the machine has his feet at *f d*; the foot *f* lowers the wings, and the foot *d* raises them.

The pivot *M* should have its centre of gravity out of the perpendicular so that the wings as they fall down also fall towards the man's feet; for it is this that causes the bird to move forward.

This machine should be tried over a lake, and you should carry a long wineskin as a girdle so that in case you fall you will not be drowned.

It is also necessary that the action of lowering the wings should be done by the force of the two feet at the same time, so that you can regulate the movement and preserve your equilibrium by lowering one wing more rapidly than the other according to need, as you may see done by the kite and other birds. Also the downward movement of both the feet produces twice as much power as that of one: it is true that the movement is proportionately slower.

The raising is by the force of a spring or if you wish by the hand, or by drawing the feet towards you, and this is best for then you will have the hands more free.

B 74 v.

[*With drawing*]

The manner of the rods of the wings.

How one ought to have the canes strengthened and able to bend by means of joints.

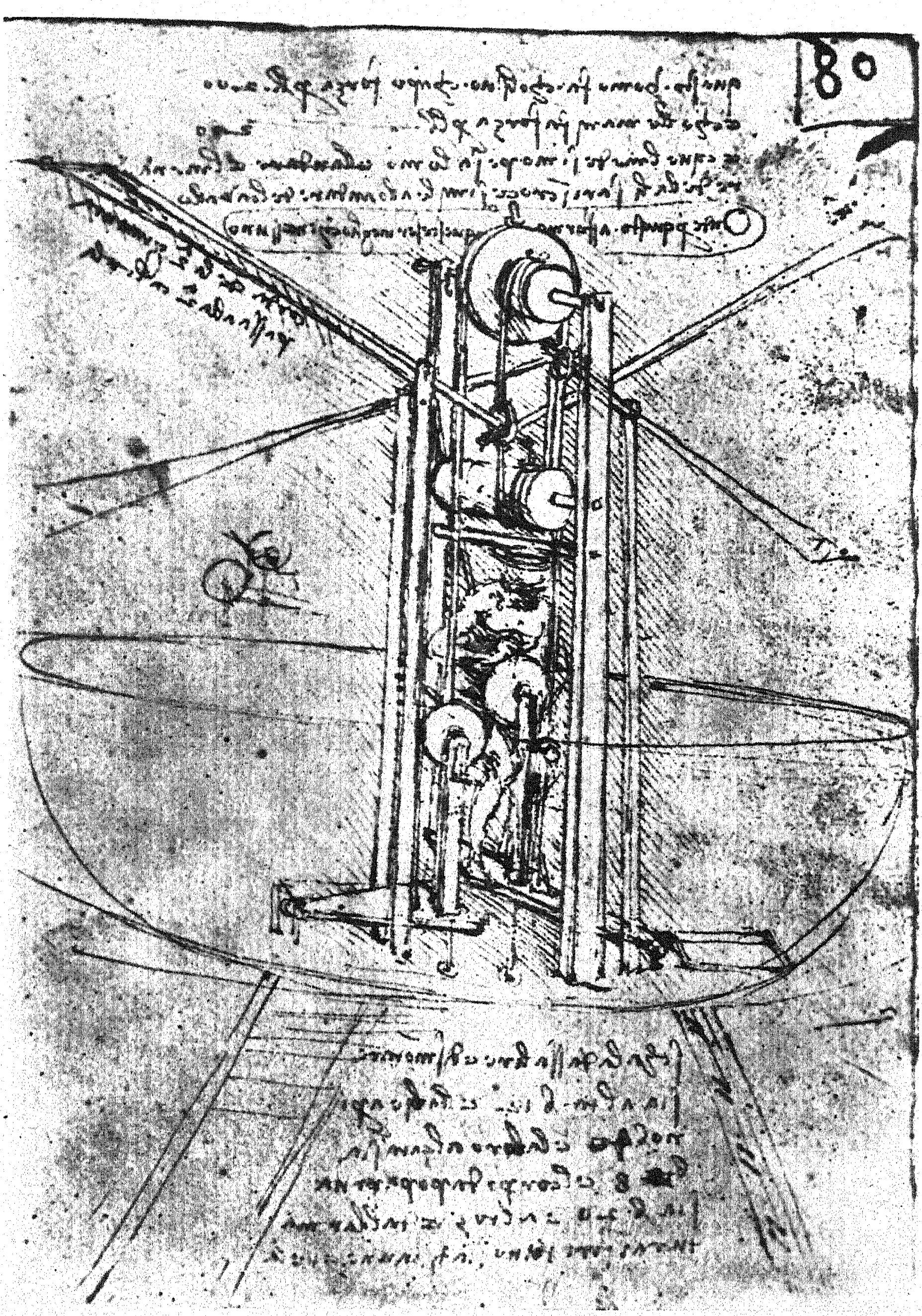
B 77 v.

[*With drawing — figure of man lying face downwards working machine*]

This can be made with one pair of wings and also with two.

If you should wish to make it with one, the arms will raise it by means of a windlass, and two vigorous kicks with the heels will lower it, and this will be useful.

And if you wish to make it with two pairs, when one leg is extended



MECHANISM OF FLYING MACHINE

Institut de France MS. B. 80 *r*

[Text : I. 516]

it will lower one pair of wings and at the same time the windlass worked by the hands will raise the others, helping also considerably those that fall, and by turning the hands first to the right and then to the left you will help first the one and then the other. This instrument resembles the large one on the opposite page (B 80 r.) except that in this the traction is twisted on the wheel *M* and goes to the feet.

In place of the feet you should make a ladder in three parts of three poles of fir, light and slender, as is represented here in front, and it should be ten braccia in length.

B 79 r.

[*With drawing—figure of man lying face downwards working machine*]

Under the body between the pit and the fork of the throat should be a chamois skin and put it there with the head and the feet.

Hold a windlass with the hands and with feet and hands together you will exert a force equal to four hundred pounds, and it will be as rapid as the movement of the heels.

B 79 v.

[*With drawing—figure of man in vertical position working machine*]

This man exerts with his head a force that is equal to two hundred pounds, and with his hands a force of two hundred pounds, and this is what the man weighs.

The movement of the wings will be crosswise after the manner of the gait of the horse.

So for this reason I maintain that this method is better than any other.

Ladder for ascending and descending; let it be twelve braccia high, and let the span of the wings be forty braccia, and their elevation eight braccia, and the body from stern to prow twenty braccia and its height five braccia and let the outside cover be all of cane and cloth.

B 80 r.

[*With drawing of screw revolving round vertical axis*]

Let the outer extremity of the screw be of steel wire as thick as a cord, and from the circumference to the centre let it be eight braccia.

I find that if this instrument made with a screw be well made—that is to say, made of linen of which the pores are stopped up with starch—and be turned swiftly, the said screw will make its spiral in the air and it will rise high.

Take the example of a wide and thin ruler whirled very rapidly

in the air, you will see that your arm will be guided by the line of the edge of the said flat surface.

The framework of the above-mentioned linen should be of long stout cane. You may make a small model of pasteboard, of which the axis is formed of fine steel wire, bent by force, and as it is released it will turn the screw.

B 83 v.

[*With drawing*]

If you wish to see a real test of the wings make them of pasteboard covered by net, and make the rods of cane, the wing being at least twenty braccia in length and breadth, and fix it over a plank of a weight of two hundred pounds, and make in the manner represented above[1] a force that is rapid; and if the plank of two hundred pounds is raised up before the wing is lowered the test is satisfactory, but see that the force works rapidly, and if the aforesaid result does not follow do not lose any more time.

If by reason of its nature this wing ought to fall in four spaces of time and you by your mechanism cause it to fall in two the result will be that the plank of two hundred pounds will be raised up.

You know that if you find yourself standing in deep water holding your arms stretched out and then let them fall naturally the arms will proceed to fall as far as the thighs and the man will remain in the first position.

But if you make the arms which would naturally fall in four spaces of time fall in two then know that the man will quit his position and moving violently will take up a fresh position on the surface of the water.

And know that if the above-named plank weighs two hundred pounds a hundred of these will be borne by the man who holds the lever in his hand and a hundred will be carried upon the air by the medium of the wing.

B 88 v.

Make the ladders curved to correspond with the body.

When the foot of the ladder *a* touches the ground it cannot give a blow to cause injury to the instrument because it is a cone which buries itself and does not find any obstacle at its point, and this is perfect.

[1] In the drawing the figure of a man is seen working a lever.

ARMOURED CAR. SCREW PROPELLER OF FLYING MACHINE

Institut de France MS. B. 83 *v*

[Text: I. 517]

Make trial of the actual machine over the water so that if you fall you do not do yourself any harm.

These hooks that are underneath the feet of the ladder act in the same way as when one jumps on the points of one's toes for then one is not stunned as is the person who jumps upon his heels.

This is the procedure when you wish to rise from an open plain: these ladders serve the same purpose as the legs and you can beat the wings while it is rising. Observe the swift, how when it has settled itself upon the ground it cannot rise flying because its legs are short. But when you have raised yourself, draw up the ladders as I show in the second figure above.

B 89 r.

[*Artificial wings*]

In constructing wings one should make one cord to bear the strain and a looser one in the same position so that if the one breaks under the strain the other is in position to serve the same function.

H 29 v.

[*Artificial wings*]

SHUTTERS IN FLYING MACHINES

The smaller these shutters the more useful are they.

And they will be protected by a framework of cane upon which is drawn a piece of gauze and as it slants upward the movement of the whole is transversal, and such lines of shutters come to open by a slanting line and consequently the process of rising is not impeded.

L 57 v.

HELM OF FLYING MACHINES

Here the head *n* is the mover of this helm, that is that when *n* goes towards *b* the helm becomes widened, and when it goes in the opposite direction the tail is contracted; and similarly when *f* is lowered the tail is lowered on this side, and so lowering itself on the opposite side it will do the same.

Of necessity in flight at uniform altitude the lowering of the wings will be as great as their elevation.

L 59 r.

When the mover of the flying body has power divisible in four through its four chief ministering members, it will then be able to employ them equally and also unequally and also all equally and all unequally, according to the dictates of the various movements of the flying body.

If they are all moved equally the flying body will be of regular movement.

If they are used unequally, as it would be in continuous proportion, the flying body will be in circling movement.

L 60 V.

Suppose that here there is a body suspended, which resembles that of a bird, and that its tail is twisted to an angle of various different degrees; you will be able by means of this to deduce a general rule as to the various twists and turns in the movements of birds occasioned by the bending of their tails.

In all the varieties of movements the heaviest part of the thing which moves becomes the guide of the movement.

L 61 V.

XIX

Movement and Weight

'Force with material movement and weight with percussion are the four accidental powers in which all the works of mortals have their being and their end.'

Speak first of the movement then of the weight because it is produced by the movement, then of the force which proceeds from the weight and the movement, then of the percussion which springs from the weight the movement and often from the force.

C.A. 155 v. b

The action of a pole drawn through still water resembles that of running water against a stationary pole.

C.A. 79 r. c

Nothing that can be moved is more powerful in its simple movement than its mover.

C.A. 91 v. b

WHERE THE SCIENCE OF WEIGHTS IS LED INTO ERROR BY THE PRACTICE

The science of weights is led into error by its practice, and in many instances this is not in harmony with this science nor is it possible to bring it into harmony; and this is caused by the poles of the balances by means of which the science of such weights is formed, which poles according to the ancient philosophers were placed by nature as poles of a mathematical line and in some cases in mathematical points, and these points and lines are devoid of substance whereas practice makes them possessed of substance, since necessity so constrains as needful to support the weight of these balances together with the weights which are reckoned upon them.

I have found that the ancients were in error in their reckoning of weights, and that this error has arisen because in a considerable part of their science they have made use of poles which had substance and in a considerable part of mathematical poles, that is such as exist in the mind or are without substance; which errors I set down here below.

C.A. 93 v. b

OF MOVEMENT AND WEIGHT

In equal movements made in equal time the mover will always have more power than the thing which is moved. And the mover will be so much the more powerful than the thing moved in proportion as the movement of this thing moved exceeds the length of movement of its mover; and the difference of the power of the mover over that of the

thing moved will be so much less in proportion as the length of the movement made by the thing moved is less than the movement of this mover.

But observe, O reader, that in this case you must take count of the air which becomes so much the more condensed in front of the thing moved as this thing moved is of greater speed; for this air is capable of being condensed in an infinite degree. This however could not happen with the movements made by things which are moved within water, for this is not capable of being condensed, as may be proved by placing it in a vessel with a narrow mouth, since for lack of the knowledge of some motive power you will not be able to place within it more than the natural capacity the vessel will contain. And it is just the contrary with the air, for if it is forced into vessels with very narrow mouths which contain a quantity of water, and the vessel is tilted at such an angle that the water shut up in it is between the mouth of the vessel and the air which has been condensed, the power of the condensed air drives the water of the vessel with such fury as to penetrate through the air for some distance, until the air that remains in the vessel can return to its first natural state.

But to return to our proposition, we may say that among movable things of the same gravity that one will have the slower movement of which the front that cleaves the air takes up more space; and so conversely as it occupies less air, not however extending itself in such a degree of thinness as to cause its weight to fail, for where there is no weight there is no local movement through the air.

There can be no local movement through the air unless it proceeds from greater or less density than the density of this air.

And if my opponent should maintain that the density which the condensed air acquires in front of the thing moved is the same in front of the mover, and is so much the more in the case of the mover in proportion as it comes in contact with a greater quantity of air in front of itself when struck and condensed than does the thing moved by it, as we see with a hand when it throws a stone through the air: the answer to this is that it is impossible for the movement of the mover added to the movement of the thing moved to be either swifter or less swift than the movement made by the thing moved, nor can it ever be that in any part of its accidental movement its speed equals that of its mover; and this is proved in the accidental movement, where the thing moved lessens its

speed at every stage of its movement, although the percussion of the thing moved is greater at some distance from the mover than it is when close at hand.

And this we see with an arrow from a bow when its point is resting against wood, for though the cord drive it with all the force of the bow it only penetrates the wood a very little distance, but does the contrary if it has some movement. Some say that the arrow in moving propels a wave of air in front of itself, and that this wave by means of its movement prevents the course of the arrow from being impeded. This is incorrect however because everything which is moved exhausts and impedes its mover. The air therefore which passes in waves in front of the arrow does so because of the movement of this arrow, and it lends little or no help of movement to its mover, which has to be moved by the same mover, but rather checks and shortens the movement of the thing moved.

The impetus generated in still water has a different effect from that generated in still air. This is proved from the fact that water in itself is never compressed by means of any movement made below its surface, as the air is within itself when struck by a moving thing. And this we may readily learn from the bubbles with which the water is encumbered from its surface to its bed, which cluster round about as the water fills up the vacuum of itself that the fish leaves behind it as it penetrates; and the movements of this water strike and drive this fish, because water only has weight within water when it has movement, and this is the primary cause of the increase of movement for its mover.

C.A. 108 r. a

I find that force is infinite together with time; and that weight is finite together with the weight of the whole globe of the terrestrial machine.

I find that the stroke of indivisible time is movement, and that this movement is of many varieties, namely natural, accidental and participating; and this participating movement ends its greatest power when it changes from the accidental to the natural, that is in the middle of its course; and the natural is more powerful at the end than in any other place; the accidental is strongest in the third and weakest at the close.

C.A. 117 r. c

Weight, force, a blow and impetus are the children of movement because they are born from it.

Weight and force always desire their death, and each is maintained by violence.

Impetus is frequently the cause why movement prolongs the desire of the thing moved.

C.A. 123 r. a

Of water of uniform weight, depth, breadth and declivity that portion is swifter which is nearest the surface; and this occurs because the water that is uppermost is contiguous to the air, which offers but little resistance through its being lighter than the water; and the water that is below is contiguous to the earth, which offers great resistance through being immovable and heavier than water. It follows that the part which is more distant from this base has less resistance than that above which is contiguous to the air, for this is light and mobile.

C.A. 124 r. a

Gravity and levity are accidental powers which are produced by one element being drawn through or driven into another.

No element has gravity or levity within its own element.

C.A. 131 r. b

If all the bed of the sea were covered with men lying down these men would sustain the whole of the element of water, consequently each man would find that he had a column of water a mile long upon his back. For if the whole sea is all supported upon its bed each part of the bed sustains its part of the water.

C.A. 153 r. a

Impetus at every stage of time becomes less by degrees, and the prolongation of its essence is caused by the air or the water, which closes up behind the movable thing, filling up the vacuum which the movable thing that penetrates it leaves of itself. And this air is more powerful to strike and compress the movable thing by direct percussion, than is the air which is so placed as to resist the penetration of this movable thing by becoming compressed; and it is this compression of the air which diminishes the fury of the aforesaid impetus in the movable thing.

Impetus is the impression of local movement transmuted from the mover to the movable thing and maintained by the air or by the water as they move in order to prevent the vacuum.

The impetus of the movable thing within the water is different from the impetus of the movable thing within the air, and these differences

result from the varieties of the aforesaid liquids, because air is condensable to infinity and water is not.

The impetus of the water is divided into two parts through its being of two natures, one of which is simple and the other complex. The simple is entirely beneath the surface of the water, the other is complex, that is it is between the air and the water, as is seen with boats.

The simple impetus does not condense the water in front of the movement of the fish, but moves the water behind the movement of the fish with the same speed that the mover has; and the wave of the water that is over against it will never be swifter than its mover.

But the movement of the boat, called complex movement because it shares with the water and the air, is divided into three chief parts because this movement is carried on in three directions, namely against the course of the river, in the direction of its current, and crosswise, that is along the breadth of the river.

C.A. 168 v. b

If the movement of the oar or of the wing be swifter than the water or the air driven by them, that amount of movement which is left in the water or the air is completed by the oar or the wing in an opposite movement.

But if the movement of this water or air be in itself swifter than that of the oar or wing this oar and wing will not move against this water or air.

And if the movement of the water or of the air be in itself of the same swiftness as that of the oar or the wing that moves in it then the oar and wing will follow the movement of the water and the air.

C.A. 175 v. b

The compression which the flame produces of itself, which increases within the resisting wall of the mortar, is that which produces the impetuous movement of its ball; and this impetus cannot be created with less density of flame or less swiftness in its rate of increase. Such swiftness of increase cannot take place within a wall of less resistance than that of this mortar. It follows therefore that the expansion which the flame makes as it rushes out of the mortar into the air, losing this density and directness of course, causes a loss of as much density as it acquires in its expansion and it ceases to follow the flight of the ball to the extent to which it bends to the . . .

C.A. 176 v. a

The movement of water within water acts as the movement of air within air.

C.A. 184 v. a

Anything which descends freely acquires fresh momentum at every stage of its movement.

If a power can move a body through a certain space in a certain time it does not necessarily follow that the half of this power will move the whole of the body over half the space in the whole of that time, or over the whole of the space in double the time.

C.A. 202 v. b

Movements are of [. . .] kinds of which the first is called temporal, because it is concerned solely with the movement of time, and this embraces within itself all the others; the second is concerned with the life of things; the third is termed mental, and this resides in animated bodies; the fourth is that of the images of things which are spread through the air in straight lines: this class does not appear to be subject to time, for it is made indivisible in time and that which cannot be divided in the mind is not found among us; the fifth is that of sounds which proceed through the air, and this will be treated of later, as also of odours and savours, and this we may call movement of the senses; the other is called material movement, concerning which we shall make our treatise.

But we shall define movements merely as being of two kinds, of which one is material and the other incorporeal, because it is not perceptible to the visual sense, or we may say that the one is visible the other invisible, although among the invisible movements there are a considerable number of material movements, such as the movement of Saturn, and as there would be with a number of wheels revolving. Wherefore we may say that the two kinds of movement are such that the one is that which is united with bodies the other with the spirit. But among these movements that of the images of things amid the air is swiftest, because it covers a great space at the same time as it is very brief, and this loses [. . .] through distance, because the air thickens; the second is that of the mind.

Of the movements of the senses we will only mention that of hearing because it operates in visible bodies, and works by means of time, as is shown in noises, peals of thunder, sounds and voices. Of smell taste

and touch we will not speak, because they do not form part of our subject.

Also one might speak of the influences of the planets and of God.

C.A. 203 v. a

THE HEAVIEST PART OF A MOVABLE BODY BECOMES THE GUIDE OF ITS MOVEMENT

If a power moves a weight a certain distance in a certain time the same power will move the half of this weight double the distance in the same time.

Or this whole power [will move] all the weight half the distance in half the time, or the whole power in the same time will move double the weight half the distance, or the whole power in half the time [will move] the whole weight half the distance.

C.A. 212 v. b

WHAT IS IMPETUS?

Impetus is a power transmitted from the mover to the movable thing, and maintained by the wave of the air within the air which this mover produces; and this arises from the vacuum which would be produced contrary to the natural law if the air which is in front of it did not fill up the vacuum, so causing the air which is driven from its place by the aforesaid mover to flee away. And the air that goes before it would not fill up the place from which it is divided if it were not that another body of air filled up the place from whence this air was divided; and so of necessity it follows in succession. And this movement would continue to infinity if the air were capable of being condensed to infinity.

C.A. 219 v. a

WHAT DIFFERENCE THERE IS BETWEEN FORCE AND WEIGHT

Force is spiritual essence which by fortuitous violence is united to weighty bodies, restrained from following their natural inclination, in which, although of brief duration, it nevertheless often shows itself of marvellous power.

C.A. 253 r. c

[*A hymn to force*]

Force is all in the whole of itself and all in every part of itself.

Force is a spiritual capacity, an invisible power which is implanted by accidental violence in all bodies that are withheld from their natural inclination.

Force is nothing else than a spiritual capacity, an invisible power which is created and implanted by accidental violence by sensible bodies in insensible ones, giving to these a semblance of life; and this life is marvellous in its workings, constraining and transforming in place and shape all created things, running with fury to its own destruction, and producing different effects in its course as occasion requires.

Tarrying makes it great and quickness makes it weak.

It lives by violence and dies from liberty.

It transforms and constrains every body with change of position and form.

Great power gives it great desire of death.

It drives away with fury whatever opposes its destruction.

Transmuter of various forms.

Lives always in hostility to whoever controls it.

Always sets itself against natural desires.

From small beginnings it slowly becomes larger, and makes itself a dreadful and marvellous power.

And constraining itself it constrains everything.

. . . dwells in bodies which are kept away from their natural course and use.

. . . willingly consumes itself.

. . . force is all in all and all through all the body where it is produced.

. . . Power (. . .nza) [potenza?] is only a desire of flight.

Always it desires to grow weak and to spend itself.

Itself constrained it constrains every body.

Without it nothing moves.

Without it no sound or voice is heard.

Its true seed is in sentient bodies.

Weight is all in all its vertical obstacle and all in every part of it.

If the oblique obstacle opposed to the weight is loosened and free it will not make any resistance to this weight but will fall down with it in ruin.

Weight naturally passes to its desired position.

Every part of this force contains the whole opposite to weight.

And often they are victors one over the other.

They are in the grip of the same natural law, and the more powerful conquers the less.

Weight changes [its position] unwillingly and force is always on the point of fleeing.

Weight is corporeal and force is incorporeal.

Weight is material and force is spiritual.

If the one desires flight from itself and death, the other wishes for stability and permanence.

They are often producers one of another:

If weight brings forth force and force weight.

If weight conquers force and force weight.

And if they are of like nature they make long company.

If the one is eternal the other is fleeting.

C.A. 302 v. b

OF THE PROPORTION OF FORCE AND MOVEMENT

I ask whether if an arrow is shot from a cross-bow [a distance of] four hundred braccia a cross-bow made in the same proportions but of four times the force and size will not send the arrow four times as far.

I ask if you have cross-bows, of equal weight, and elevated in these various thicknesses, [*diagram*] of the same length, what effect will it make in the distances upon the same arrow.

And if a cross-bow sends an arrow weighing two ounces a distance of four hundred braccia how many braccia will it send one of four ounces?

Force

Force cannot exist in bodies without either force or weight together with movement.

Force is caused by violent movement by means of weight or other force.

If a thing which moves continuously is given fresh momentum by greater movement the thing moved redoubles the velocity of its movement: for example a revolving wheel, such as the potter's lathe which revolves; — by adding to it the movement of the foot this wheel becomes swifter; also if a ball moving in a certain direction be struck by the player along the line of its movement this movement will be accelerated.

C.A. 314 v. b

THE MOVEMENT OF A HEAVY SUBSTANCE

The movement made by a spherical heavy substance in the air.

There are two movements which can be made by a spherical heavy substance in the air, one of which is called simple, the other compound,

Simple is that movement in which the surface of the movable thing moves as much as its centre; compound is that in which the surface of the movable thing is in itself more swift than its centre.

Simple movement

Simple movement is that in which the movable thing moves equally in every part.

In compound movement there is no part which moves with a movement equal to that of the whole, unless it is the diameter, which makes itself the seat of the revolving movement.

The compound movement is transformed into as many different aspects as there are different sides with which it strikes against the obstacles that are in its path.

The simple movement is changed into compound movement, if its movement is impeded in any part of its sides.

In a long course compound movement made in the air resolves itself into simple movement; and the fact of this happening makes it more certain that the cause of the simple movement is also the cause of the compound movement; and this is shown in every wheel to which the revolving impulse is imparted, for it endures but little and is constantly growing less.

C.A. 315 r. a

Every impetuous movement bends towards the less resistance as it flies from the greater.

C.A. 315 r. b

Force is caused by the movement of the lever in its counterlever, and by this it is infused into the bodies which it moves.

C.A. 316 v. b

Every heavy substance not held back out of its natural place desires to descend more by a direct line than by an arc. This is shown because every body whatever it may be, that is away from its natural place, which preserves it, desires to regain its first perfection in as brief a space of time as possible; and since the chord is described in a less time than the arc of the same chord it follows from this that every body which is away from its natural place desires to descend more speedily by a chord than by an arc.

From this three things follow: — the first is that the movement of gravity in the balance is not entirely natural. This is evident from the

fact that the arms of this balance as they descend describe an arc, and as a consequence curved lines. The second is that the heavy movement in the arm of the balance which descends is not entirely violent, since in this manner it acquires in its descent natural movement.

The third is that the heavy movement in the balance is half-way between the natural and the violent.

This is evident seeing that every natural movement is violent or indeed is beyond nature. C.A. 335 v. f

Among bodies of varying substance and of similar shape that which has most weight descends most rapidly.

Proposition

That spherical and heavy body is of the slowest movement in which the contact that it makes with the plane where it touches is nearest to the perpendicular drawn from its centre. C.A. 338 r. b

Weight. [*With diagrams*]

The middle of each weight is in a perpendicular line with the centre of its support.

When a man standing or sitting takes a weight in his arms it is necessary for the support on which he is resting to be in the middle between this weight and himself.

It is impossible for the force exerted by a man's arm to be able with the weight supported by it to extend beyond the upright position without the counter action of the above named opposite weight.

Suppose you were to say: — I wish to lean my whole back against a wall, and sit on the ground with legs extended in such a way as to touch the whole corner with legs and back, and I will take a weight in my hands and bring it near to me and move it away with the actual force of my arms, and I shall not be moving my back or my head or any part of me so as to create any counterpoise to the weight moved by my arms, and nevertheless this will be done effectively.

To this I reply that the effect which the force exerts will not in this case extend to any other function than that of keeping the arms united with the trunk, as though without flexible joints and in one single piece, making this piece like a bar of iron bent in two right angles, the extremity of the upper part carrying itself in a perpendicular line as far

as the middle of the base or the opposite lower part, and if there is the burden of a weight superimposed upon this upper extremity this weight will exert force below itself upon the perpendicular line of its base.

C.A. 349 r. b

A man about to give a great blow with his arms so places himself that all his power is on the opposite side to that of the place at which he intends to strike, for the thing which moves most exerts most power upon the thing that resists the movement.

C.A. 352 v. c

Every impression is preserved for a time in its sensitive object; and that which was of greater power will be preserved in its object for a longer time, and for a shorter time with the less powerful.

In this connection I apply the term sensitive to such object as by any impression is changed from that which was at first an insensitive object;—that is one which, while changing from its first state preserves within itself no impression of the thing which has moved it. The sensible impression is that of a blow received upon a resounding substance, such as bells and suchlike things, or like the note in the ear, which, indeed, unless it preserved the impression of the notes, could never derive pleasure from hearing a voice alone; for when it passes immediately from the first to the fifth note the effect is as though one heard these two notes at the same time, and thus perceived the true harmony which the first makes with the fifth; but if the impression of the first note did not remain in the ear for an appreciable space of time, the fifth, which follows immediately after the first, would seem alone, and one note cannot create any harmony, and consequently any song whatsoever occurring alone would seem to be devoid of charm.

So, too, the radiance of the sun or other luminous body remains in the eye for some time after it has been seen; and the motion of a single firebrand whirled rapidly in a circle causes this circle to seem one continuous and uniform flame.

The drops of rain water seem continuous threads descending from their clouds; and so herein one may see how the eye preserves the impressions of the moving things which it sees.

The insensitive objects which do not preserve the impressions of the things which are opposite to them are mirrors, and any polished substance, which, so soon as ever the thing of which it bears the impression

is removed from before it, becomes at once entirely deprived of that impression. We may, therefore, conclude that it is the action of the mover pressing against the body moved by it which moves this body in the direction in which it moves.

Amongst the cases of impressions being preserved in various bodies we may also instance the wave, the eddies of the water, the winds in the air, and a knife stuck into a table, which on being bent in one direction and then released, retains for a long time a quivering movement, all its movements being reciprocal one of another, and all may be said to be approaching towards the perpendicular of the surface where the knife is fixed by its point.

The voice impresses itself through the air without displacement of air, and strikes upon the objects and returns back to its source.

The concussion of liquid with solid bodies is of a different character from the above-mentioned cases of concussion; and the concussion of liquid with liquid also varies from the foregoing.

Of the concussion of solid with liquid there is seen an example in the shores of the ocean, which receive the waters full on their rocks and hurl them against the steep crags; and oftentimes it happens that before the course of the wave is half completed, the stones carried by it return to the sea from whence they came; and their power of destruction is increased by the might of the wave which falls back from the lofty cliffs.

C.A. 360 r. a

Force never has weight, although it often performs the function of weight.

The force is always equal to the weight which produces it.

This is proved by the . . .

C.A. 382 r. a

That body weighs less upon the air which rests upon a greater expanse of air. We may take as an example the gold from which money is made which is extremely heavy, but which when spread out in fine leaf for gilding maintains itself upon the air with each slightest movement of this air.

[*With drawing*]

The hollows of the wings underneath the shoulders receive the revolution of the air near the starting point of the wings, and nature has

so conditioned them near to the starting point of these wings by the fourth proposition concerning weight where it is stated that that part of the support is most powerful which is nearest to its starting point.
C.A. 395 r. b

No element when united will have weight within its element; therefore the parts of the air do not weigh upon the lower parts.

No body of dissimilar quality will come to rest within this if it is at liberty, because as this body has not the same quality as the air it must needs be either heavier or lighter, and if it is heavier it will drop down, and if lighter it will penetrate upward.

That thing which has most conformity with the element that surrounds it will issue forth from it with the slowest movement.

And the thing which is most unlike will separate itself from it with more impetuous movement.

When the force generates swifter movement than the flight of the unresisting air this air becomes compressed after the manner of feathers pressed and crushed by the weight of the sleeper. And that thing which drove the air finding resistance in it rebounds after the manner of a ball struck against a wall.
Tr. 10 a

The line that is straightest offers most resistance.
Tr. 24 a

That thing which within the line of equality shall find itself at a greater distance from its support will be less sustained by it, as is shown below in *m n* [*diagram*].

That thing which is at a greater distance from its support will be less sustained by it, and consequently will fulfil its natural desire with greater liberty.

Violent movement the more it is exerted the more it grows weaker: natural movement does the opposite.

That thing which is at a greater distance from its support will be less sustained by it: being less sustained it will partake more of its liberty, and since the weight that is free always descends the thing therefore being weighty will descend more swiftly.

That part of the pole which is farther from its support will be less sustained by this support. Being less sustained it continues to follow its nature more freely, and this being heavy and the nature of heavy things

being to desire to descend it will therefore descend more swiftly than any other part.

Tr. 30 a

The air is capable of compression and water is not; and when the movements which drive it are swifter than the flight of this air, as the part which is more caught by its mover becomes denser and consequently offers more resistance; and when the movement made in it is more rapid than the escaping power of this air its mover comes to take a contrary movement. As is shown in the case of the birds which are not able to drive the points of their wings downwards with the speed with which they are moving, because their motive power moves them so much the less as the bird raises itself up as the extremity of the wing fails to go down. After the fashion of the man who keeps hands and breast close to a wall and presses with his hands upon this wall so that if the wall does not give way the man must needs turn back.

Tr. 42 a

[*Sketches*]

That part of the cloth that is farthest away from its support will surrender itself most to the movement of the wind.

That earth which is most mixed with water will offer least resistance to weights placed upon it.

That water which is most intermingled with earth will offer resistance to greatest weight.

Tr. 60 a

OF THE BLOW

Everything hit against a resisting object leaps back from this object at an angle equal to that of the percussion.

Note concerning water. [*Diagram*]

The same is proved in the tenth proposition of the book concerning the nature of the blow where it treats of the ball struck against a wall. And if you wish to know the depth of a fall of water observe the line of the fall in *c b*, of what degree of slant it shows itself; then observe the part that lies between the point of impact *b* and the point *a* to which it rises; and make the angle *a b d* and measure how it is shown in the tenth of Percussion. And if you should be of opinion that the water in this case would not be able to deflect owing to some resisting object inter-

vening in the line of its recoil know that if the fall is of long continuance it will have worn away every obstacle which was set in the path of its springing force. Tr. 66 a

AGAINST PERPETUAL MOTION

No inanimate object will move of its own accord; consequently when in motion it will be moved by unequal power, unequal that is in time and velocity, or unequal in weight; and when the impulse of the first motive power ceases the second will cease abruptly. A 22 v.

[*Of force and spherical body*]

Every spherical body of thick and resisting surface when moved by a like force, will make as much movement in the rebounds caused by its impact upon a concrete ground as if it were thrown freely through the air.

How admirable Thy justice, O Thou First Mover! Thou hast not willed that any power should lack the processes or qualities necessary for its results; for if a force have the capacity of driving an object conquered by it a hundred braccia, and this object while obeying it meets with some obstacle, Thou hast ordained that the force of the impact will cause a new movement which by divers rebounds will recover the entire amount of the distance it should have traversed.

And if you were to measure the track made by these bounds you will discover it to be of the same length as it would be if a similar object were impelled freely through the air by the same force.

You may make an experiment of this with a small glass ball as it strikes upon a surface of smooth polished stone. Take a long staff and mark it with different colours from end to end, and then give it someone to hold, and set yourself at some distance away [to watch] the rebounds [and see] against the height of the staff to what colours the ball rises successively with each rebound, and make a note of them. If there are as many observers as the number of times the ball rebounds each will keep it more easily in memory. But either have the staff fixed at the top or with the end in a hole, for if anyone held it with his hand he would interrupt the line of sight of the judge. Arrange that the first bound be made between two right angles so that the ball may always fall in the same spot, because then the height of the rebounds against the staff may be more accurately discerned.

Then have this ball discharged by the same power in free course and make a note of the spot where it strikes; and measure it and you will find that the length of the second course is identical with the first.

A 24 r.

If you should be in a boat, and you there exert your utmost force, the boat will never stir from its position unless the said force has a greater obstacle outside this boat than that made within it.

Again if you are all huddled up in a sack and within it make efforts to move yourself you will find it impossible to change your position, but if you draw a foot out of the sack and use it as a lever on the ground putting your head to the bottom of the sack you will be able to draw it off backwards.

The flame also does the same with its desire to multiply and extend itself in the bombard, for while it is entirely inside it the bombard does not recoil. But when this flame strikes and pushes the resisting air while remaining united to that which pushes on the bottom, it is the cause of the bombard recoiling; for that portion of the flame that strikes, not being able to find in the air that instant passage that it requires, throws its force upon the opposite side.

A 28 r.

WHAT IS FORCE?

Force I define as an incorporeal agency, an invisible power, which by means of unforeseen external pressure is caused by the movement stored up and diffused within bodies which are withheld and turned aside from their natural uses; imparting to these an active life of marvellous power it constrains all created things to change of form and position, and hastens furiously to its desired death, changing as it goes according to circumstances. When it is slow its strength is increased, and speed enfeebles it. It is born in violence and dies in liberty; and the greater it is the more quickly it is consumed. It drives away in fury whatever opposes its destruction. It desires to conquer and slay the cause of opposition, and in conquering destroys itself. It waxes more powerful where it finds the greater obstacle. Everything instinctively flees from death. Everything when under constraint itself constrains other things. Without force nothing moves.

The body in which it is born neither grows in weight nor in form. None of the movements that it makes are lasting.

It increases by effort and disappears when at rest. The body within

which it is confined is deprived of liberty. Often also by its movement it generates new force.

A 34 V.

Every weight desires to descend to the centre by the shortest way; and where there is the greater weight there there is the greater desire, and that thing which weighs the most if it is left free falls most rapidly. The less the slant of the opposing substance the greater its resistance. But the weight passes by nature into all that supports it, and thus penetrating from support to support it grows heavier as it passes from body to body until it realises its desire. Necessity draws it and abundance drives it away. It is all in all its vertical opposition and all in each of its degrees. And that opposition which slants the most will not offer resistance to its descent, but, being free, will fall together with it. In its function of pressing and making heavy it is like force. Weight is subdued by force, as force is by weight. One can see weight without force, but one cannot see force without weight. If weight has no neighbour it seeks one with fury and force drives it away with fury. If weight desires an unchangeable position force readily flies from it. If weight desires stability and force is always desirous of flight, weight of itself is without fatigue, while force is never exempt from it.

The more weight falls the more it increases and the more force falls the more it diminishes. If one is eternal, the other is mortal. Weight is natural and force is accidental. Weight desires stability and permanence, and force desires flight and death of itself. Weight, force and a blow resemble each other in respect of pressure.

A 35 r.

In the centre of the direct path taken by heavy bodies which traverse the air with violent movement, there is greater power and greater striking force when an obstacle is met with than in any other part of its line.

The reason of this is that when the weight parts from the force of its mover, although this separation is in the initial stage of its power, it finds nevertheless the air without movement, and finds it in the initial stage of its resistance, and although the sum total of the resistance of the air is greater than the power of the weight which is pushed upon it, nevertheless as it strikes only a small part it succeeds in remaining the conqueror. Consequently it drives it from its place and in so driving it it somewhat impedes its own velocity. This air therefore after having been

pushed pushes and drives the other, and generates revolving movements in its wake, of which the weight that is moved within it is always the centre, after the fashion of circles formed in the water, which have their centre at the spot struck by the stone. And so as the one circle drives the other, the whole air that is along the line in front of its mover becomes prepared for movement, and this increases in proportion as the weight that drives it presses the more. In consequence this weight finding less resistance in the air redoubles the speed of its course, the same as a barge drawn through the water, which moves with difficulty at the beginning of the movement although the force of its mover may be at its maximum, but as with arched waves this water commences to take its movement the barge in following this movement meets only with slight resistance and therefore moves with greater ease. The bullet likewise finding but slight resistance follows the course it has begun until the point at which abandoned in part by its first force it commences to grow weak and to drop, and as its course changes the way already prepared for its flight by the fleeting air contains it no longer; the more it drops however the more it finds fresh resistance in the air and the more it delays, up to the point at which resuming its natural movement it acquires fresh speed, and even so the barge as it turns delays its course. Now therefore I conclude according to what is demonstrated in the eighth proposition that that part of the movement which occurs between the first resistance of the air and the beginning of its drop is of the greater power, and it is the centre of the course made in the air in a straight direct line.

A 43 V.

OF THE BLOW AND THE DISPLACEMENT CAUSED BY WEIGHT OR BY FORCE

I maintain that the displacement caused by the weight which falls is equal to the displacement caused by the force.

The body that receives the blow is not injured in the part opposite as it is in the part which is struck. The proof of this is shown when a stone is struck while lying in a man's hands, for the hand is not injured when it is holding the stone that is struck as much as it would be injured if it actually received the blow.

A 53 V.

DEFINITION OF FORCE AND MOVEMENT IN ANIMALS

I affirm that the said movement is based upon several points of support.

Force is produced by the lessening and contraction of the muscles which draw back, and of the nerves which stretch as far as the sensation communicated by the empty cords dictates.

B 3 v.

OF THE NATURE OF MOVEMENT

If a wheel of which the movement has become very rapid continues to make many revolutions after its motive power has abandoned it, then if this motive power continues to cause it to turn with the same quickness of movement, it would seem that this continuance necessitates but little force.

And I conclude that in order to maintain this movement only a slight effort by the motive power would be needed, and so much more as by nature it tends to become fixed.

B 26 v.

CONCERNING WEIGHTS

I ask if a weight of a pound falling two braccia bury itself in the earth the depth of a hand how deeply will it bury itself if it falls forty braccia, and how far a weight of two pounds will bury itself if it falls two braccia?

One may ask also if the size of this weight be represented by a quantity *a* and then this quantity be doubled, its weight remaining the same and falling from the same height, how much greater impress the lesser bulk will make than the greater if the ground offer equal resistance?

B 61 r.

EXAMPLE OF THE BLOW AND OF THE DIFFERENCE BETWEEN WEIGHT AND FORCE

The blow since it is of very short and even of indivisible life produces suddenly its full and quick effect upon what is opposed to it, and this effect ends before it reaches the base of the thing struck. For this reason therefore you will find more enlargement at the summit of the thing struck than at its base. And if you wish to ascertain how much greater the power of the blow is upon the thing struck at its summit than at its base, calculate how many times the circumference of the base *m n* will go into that of the summit *a c*; as many times as *m n* goes into *a c* so many times will *a c* receive into itself greater force than *m n*. But if this support *a m* is pressed down by weight or by force, *m n* will be as much enlarged as *a c*, because their powers move more slowly than that of the blow.

Ç 6 v.

The Blow

Since the blow is more swift than the movement, the thing touched by the blow although it may be in movement will rather obey the effect of this blow than that which accelerates the movement.

c 7 r.

If two make the same journey in the same time he who runs often, with frequent intervals for rest, will undergo as much fatigue as he who goes gently and continuously.

c 7 v.

Percussion

If two balls strike together at a right angle one will deviate more from its first course than the other in proportion as it is less than the other.

c 15 r.

The part of a log first severed from the end of it by the stroke of the axe flies off to a greater distance than any other part carried away by the same blow.

This is because the part of the log that first receives the blow receives it in the first stage of its power and consequently goes farther. The second part flies a less distance because the fury of the blow has already subsided, the third still less and so also the fourth.

The wood which is divided from the rest by the stroke of the axe will fly off with greater violence at one time than at another as the stroke is more powerful at one time than another, and the piece will fly off to a greater distance. This is because as the blow is the most powerful and instant thing that a man can do, as is shown in the fourth proposition which treats of the nature of the blow, when the axe, driven by man's strength and by the movement of the hands in falling, from the weight and blow of the hatchet has entered within the surface of the close-grained wood, so soon as this fine edge has entered immediately the thick part of the hatchet follows and proceeds with such vigour and swiftness to widen and enlarge the edges of the cut that it pulls it asunder with great force, and the quicker it is the more the cut will be enlarged and deepened, and if (part) is entirely severed it flies from the blow with great swiftness, as may be shown by experiment.

Water air and fire produce the same effect in their rebound from objects that oppose their course:

A piece of wood separated from the rest by the blow of an axe will fly off from it at an equal angle to that of the blow.

Everything of a compact surface that falls upon a resisting object will have the line of its rebound at the same angle as the line of its incidence.

C 22 V.

Movement and percussion

Among bodies of equal movement and size that which is of greater weight will give a greater blow to the thing that opposes its course, and since turbid water is heavier than clear, the blow which it gives upon the thing that opposes its course will be greater.

Movement of water

A body with a thicker harder surface will cause the objects that strike against it to separate from it with a more powerful and rapid rebound.

Water

Water that falls upon gravel mixed with sand and earth will hollow it out more deeply and more rapidly for the aforesaid cause than if it fell upon plain soft mud, for as it falls upon gravel it takes a swift powerful leap and gnaws away more of what first opposes its bound and rises more.

The angle caused by the percussion of equal spherical bodies is always equal to that of the rebound.

C 28 R.

Every weight tends to fall towards the centre by the shortest way.

C 28 V.

OF HUMAN MOVEMENT

When you wish to represent a man in the act of moving some weight reflect that these movements would be made in different directions, that is in the case of simple movement from below upwards, as that which a man makes when he stoops to lift a weight with the intention of raising it as he straightens himself; or when he wishes to pull something backward or push it forward or draw it down with a cord that passes over a pulley. Here one should remember that a man's weight drags in proportion as the centre of his gravity is distant from that of his support, and to this must be added the force exerted by his legs and bent spine as he straightens himself.

E 15 R.

The mover is always more powerful than the thing moved.

E 20 V.

Of the knowledge of the weights proportioned to the forces of their movers:

The force of the mover ought always to be in proportion to the weight of its movable thing and to the resistance of the medium in which the weight moves. But one cannot deduce the law of this action unless one first gives the quantity of the condensation of the air when struck by any movable thing whatever; and this condensation will be of greater or less density according to the greater or less speed of the mobile thing pressing on it, as is shown in the flight of birds, for the sound that they make with their wings in beating the air is deeper or more shrill according to whether the movement of the wings is slower or swifter.

E 28 V.

The weight of every heavy thing suspended is all in the whole length of the cord that supports it and all in each part of it.

E 32 V.

OF COMPOUND IMPETUS

Compound impetus is the name given to that which participates in the impetus of the mover and the impetus of the thing moved, as is the movement *f b c* which is between two simple movements one of which is near the beginning of the movement and the other near the end: *a g* is the first and *d e c* is at the end. But the first only obeys the mover and the last is only of the semblance of the thing moved.

OF IRREGULAR IMPETUS

The irregular [dechonpossto] impetus accompanies the thing moved with three kinds of impetus, of which two spring from the mover and the third from the thing moved. The two that originate in the mover are the straight movement of the mover mingled with the curved movement of the thing moved, and the third is the simple movement of the thing moved which tends merely to turn in the middle of its convexity at contact with the plane where it turns and lays itself down.

FRICTION

Friction is divided into three parts: these are simple, compound and disordered.

Simple friction is that made by the thing moved upon the place where it is dragged. Compound is that which the thing moved makes between two immovable things. Irregular is that made by corners of different sides.

E 35 r.

OF THE WEIGHT DISTRIBUTED OVER THE LENGTH OF THE CORD WHICH SUPPORTS IT

The weight distributed over the whole length of the cord which supports it will give less strain to this cord than if it was suspended to its lowest part, and this is proved by one of the Elements which says 'Among cords of equal thickness the longest is the least strong'.

Consequently the cord *a b* which supports the weight distributed over all the remainder of the cord *b t* is so much stronger than the opposite part of the cord *a c* as it is shorter.

One cord supports as many times the weight of another as the number of the curves is greater in the one than the other.

The division made by the cord with its pulley is never rectangular; this is proved from the two simple cords that hang from the same pulley which would meet at the centre of the earth.

DIVISION OF WEIGHT

There are three conditions of gravity, of which the one is its simple natural gravity, the second is its accidental gravity, the third the friction produced by it. But the natural weight is in itself unchangeable, the accidental which is joined to it is of infinite force, and the friction varies according to the places wherein it occurs, namely rough or smooth places.

E 54 v.

DEFINITION OF COMPOUND BALANCES

We may define the nature of compound balances both as regards circular balances that is to say pulleys and wheels and also rectilinear balances. But first I will make some experiment before proceeding farther because it is my intention first to cite experience then to show by reasoning why this experience is constrained to act in this manner. And this is the rule according to which speculators as to natural effects have to proceed. And although nature commences with reason and ends in experience it is necessary for us to do the opposite, that is to commence as I said before with experience and from this to proceed to investigate the reason.

I see that it is necessary in the compound rectilinear balance in the second demonstration that as much as the one of the extremities descends so much the opposite extremity rises, and the cause of this is the equality of their arms.

E 55 r.

OF GRAVITY AND ITS SUPPORTS

Gravity suspended or supported is all in all its support and all in each of its parts.

The cord bent over its pulley supports more weight in its pendent extremities than when it is stretched out in a continuous straight line. This may be proved thus: suppose the cord bent over the said pulley to be *d c e f* and the ultimate strength of its resistance to be represented by 10; I affirm that if the same cord be stretched straight as is shown at *a b* it will not support more than five.

And this proceeds from the seventh of this where it is stated: 'Each cord gains as much in strength as it loses in length; consequently the cords *c d* and *e f* in order each to have their length double that of the cord *a b* must necessarily have double the strength of the cord *a b*.'

WHAT PART OF THE CURVED CORD IS STRONGEST

The maximum strength of the curved cord is in the middle of its bend: this is proved by the eighth of this which says 'That cord is strongest which is thickest'. It follows that as the cord is compressed in its fold over the pulley where it is bent it becomes widened and lowers itself a little, and for this cause necessity constrains it to become thus compressed.

E 55 v.

OF MOVEMENT MADE BY A HEAVY SUBSTANCE

Every heavy substance moves on that side on which it weighs most.

And the movement of the heavy substance is made on that side where it encounters least resistance.

The heaviest part of bodies that move in the air becomes the guide of their movements.

That heavy substance is of more slow descent in the air which falls in greater width.

It follows that that heavy substance will have the swiftest descent which confines itself within the least width.

The free descent of every heavy substance is made along the line of its greatest diameter.

That heavy substance will be swiftest in movement which reduces itself to the smallest bulk.

The descent of a heavy substance is as much slower as it extends in greater breadth.

E 57 r.

WHY A BALANCE FORMED OF BEAM AND EQUAL WEIGHTS STOPS IN A STATE OF EQUILIBRIUM

Every liquid heavy substance settles down with its opposite extremities in a state of equilibrium when it is of natural uniform weight. And it is lowered as much on one side as it is raised on the other and acts round its centre, as one sees with the extremities of the balance round its axis with their oscillations upwards and downwards until the impetus is consumed; and this is brought about solely through the inequality of the opposite sides round the centre of the water or of the balance.

E 57 v.

[*Gravity and movement. Balances*]

By what is said below the balance does not have all its natural weight upon the centre of its revolution, but it has as much less as the weight that moves the upper arm has the more slanting movement, as is proved in this discourse.

The heavy substance in suspension is all in all and all in every part of the centre line of its support.

The staff placed slantwise has two kinds of gravity of which one weighs slantwise between the centre of the earth and the horizon. The other weighs vertically upon the centre of the earth. And of these one is accidental and the other natural. And this occurs where the mathematical centre is not the centre of the revolution of the balance. This is proved thus, let *a b c d* be the balance and *s* its mathematical centre; the centre of the revolution will be *f*. I affirm that when the balance is in such a position the mathematical centre *s* is the same in the line that points towards the centre of the earth, that is *g h*, as the centre of the revolution *f*, and this line *g h* divides the staff of the balance into two equal and similar parts namely the part *a b e f* and the part *c d e f*. Whether one wishes to rest the balance upon the point *s* or the point *f* is immaterial for both the one point and the other are in the central line *g h* which divides the weight equally.

There still remains the above-mentioned slanting weight which is above the centre of the revolution *f*, that is the weight which is above the line *n o* that is *a b r f*, to which the counter weight *c d r f* offers no resistance in the above-mentioned slanting movement.

E 58 r.

OF THE MOVER OR THE MOVABLE THING

The power of the mover is always greater than the resistance of the thing moved.

OF LEVER AND COUNTERLEVER

There is added as much accidental weight to the mover placed at the extremity of the lever as the movable thing placed at the extremity of the counter-lever exceeds it in natural weight.

And the movement of the mover is as much greater than that of the thing moved as the accidental weight of this mover exceeds its natural weight.

This may be proved; for let us say that the movement of the mover is from *b* to *d* and of the thing moved from *a* to *c*; I maintain that the movement *b d* will be as much greater than the movement *a c* as the accidental weight of *b* exceeds the [natural] weight *b*; and as this exceeds it by one, the natural weight therefore also . . .

E 58 v.

OF WEIGHTS

A balance of equal arms and weights when removed from a position of equality will have its arms and bows unequal because it changes the mathematical centre, and consequently necessity constrains it to regain the lost equality of arm and weight. This is proved by the second passage.

Transcript of the above

A balance with equal arms and weights removed from a position of equality will make arms and weights unequal, and consequently necessity constrains it to regain the lost equality of arms and weight. This is proved by the second of this, and it is proved because the higher weight is more removed from the centre of the revolution than the lower weight, and consequently having a more feeble support it descends more easily and lifts up the opposite side of the weight joined to the extremity of the lesser arm.

OF ACCIDENTAL AS AGAINST NATURAL WEIGHT

The accidental weight set in the balance against the natural weight is worth as much as this natural weight, and this is proved by means of the weight that the pole of the balance receives from it, for it loads itself so much more with the accidental than the natural weight in proportion as the greater arm of this balance exceeds the smaller in length.

E 59 r.

THE COMMENCEMENT OF THIS BOOK CONCERNING WEIGHTS

First. If the weights, arms and movements slant equally these weights will not move each other.

Second. If the weights equal in slant, and equal, move each other the arms of the balance will be unequal; for 'Equal weights maintain equal gravity in an equal slant'.

Fourth. If the weights and the arms of the balance with the slant of the movements of these weights are equal, then these weights will show themselves unequal if their appendices have their slants unequal.

Third. But if the equal weights in the arm and the balance move one another then the movements of the weights will be of unequal slant.

First. Why it is a definition. The cord that hangs from the opposite sides of the pulley or beam where it rests, is always divided and joined in rectangular division and union by the opposite ends of the half diameters of this pulley or beam or other round instrument, no matter what the slant of the cords may be.

E 59 v.

WEIGHT AND FORCE

The potential lever will never be consumed by any power.

This is proved by the first which says: — 'Every continuous quantity is divisible to infinity'. But that which is divisible in act is also divisible in power: but it is not the case that that which is divisible in power is divisible in act. And if the divisions made potentially towards the infinite change the substance of the matter divided, these divisions will return to the composition of their whole, the parts reuniting in the same stages in which they were divided. For example let us take ice and divide it towards infinity; it will become changed into water, and from water into air, *and from air into fire*[1]; and if the air should come to thicken again it will change itself into water, and from water into hail, etc.

E 60 r.

[1] Words crossed out in MS.

A cord of any thickness or strength whatever placed in a level position as regards its opposite extrêmities will never be able to straighten itself if it has any weight placed in the centre of its length.

OF THE RESISTANCE OF THE ARCHED CORD

Given the straight cord suspended by one of its ends which breaks itself exactly where it is fastened by its own weight, one asks what weight it will support in any arch that may be made of this cord, this arch having its extremities in the position of equality.

Where the potential lever is in existence the force will also be in existence.

The force will be of so much the greater excellence as the potential lever is less in quantity.

The force is always created at the same time as the potential lever and so it dies when this lever fails.

E 60 V.

OF GRAVITY AND ITS ORDER

[*Levers real and potential*]

It is necessary first to describe the real powers in whatever aspect, second the semi-real powers, third the potential virtue. Next define how the centre of the circumvolution is that which divides the power of the lever from the power of its counter-lever.

And the movements of the lever and of its counter-lever are always contrary in their movement of circumvolution round the above-mentioned centre. And all the powers joined to the lever and counter-lever are always in rectangular conjunction with this lever both real and potential. And this angle has always one of its sides which proceeds from the centre of the circumvolution, and the real arms of the balance will never contain within themselves the potential arms unless they are in a position of equality. And always the junction of the real or potential appendix with the arm of the balance is the nearest part of this appendix.

The first direction taken by the appendix after its junction with the arm of the balance shows the direction of the potential appendix which in rectangular conjunction meets the extremity of the potential lever.

E 65 V.

Always the cords folded in an angle in which the heavy substance is supported joined to the ring will bear equally the burden of this weight

at their extremities, and this comes from the fact that the cord is of uniform slant.

The cords which with equal slant meet at the point of suspension of a heavy substance always support equally the weight of this substance.

If two cords converging or diverging descend to a suspended beam situated at any angle and are joined to it in any part of its length, so that the centre of the beam is placed between them, when these parts find themselves in these conditions the centre of gravity of the beam will be in the intercentric line which passes through this beam.

OF GRAVITY

It is impossible that the power of any motive force should be able at the same time and with the same movement to create a power greater than itself. This is proved by the third of this which says: — 'Powers which are equal to each other do not overcome each other'.

E 66 r.

If two cords descend with different lengths and with their slants converging or diverging to the point of suspension of the extremities of the beam, then if this beam be equijacent the slants of the two aforesaid cords will be equal one to the other.

E 66 v.

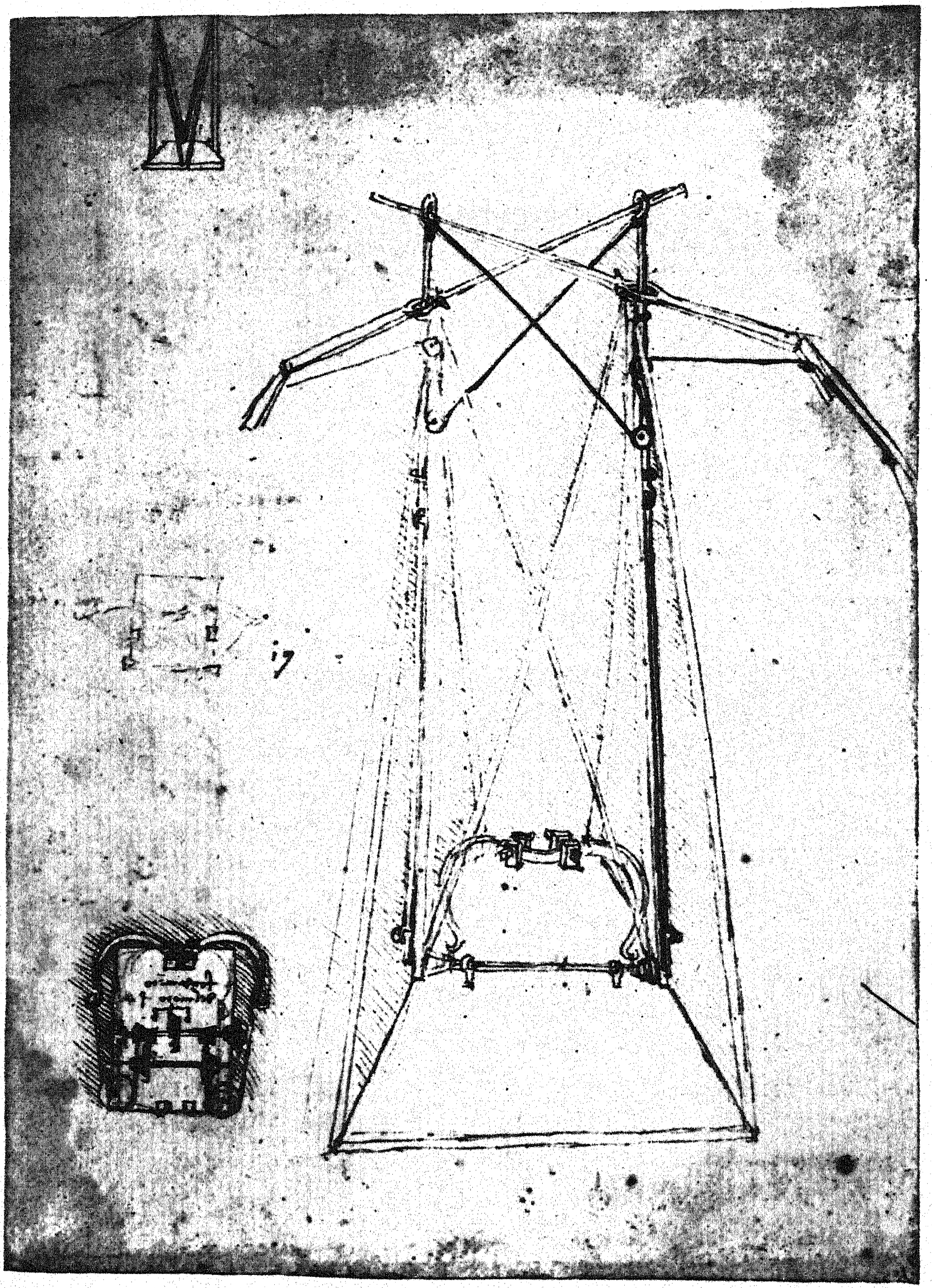
What is gravity and whether it is natural or accidental, and one may ask the same concerning levity:

The answer is that both are accidental powers because each always waits for its destruction and one is never born without the other or dies without the other. This is proved by the air which forms in the shape of a bubble or bladder at the bottom of the water, where the fact of its formation immediately creates its levity and creates the weight of the water that is above it. And as soon as the bubble arrives at the surface its levity dies together with the gravity of the water that was above it.

The stone that descends through the water first makes the water heavy that closes up the beginning of the entrance made by the stone, and makes light the water that rises to fill up the space that the stone leaves as it descends, because that which moves upwards is light.

Whether the space of the water penetrated by the stone is filled by water descending or by water from the side or by water that is below.

E 67 r.



MECHANISM OF FLYING MACHINE. 'FOUNDATION OF MOVEMENT'

MS. Codice Atlantico 314 *r.b.*

[*Of a heavy body*]

If the angle that is formed by the meeting of the two cords that support a weight is cut by the intercentric line of this weight, then this angle is divided into two other angles, and as these are divided anew by the line of the equality two triangles are then produced, and these will have the same proportion between base and base as there is between angle and angle, and the same proportion between angle and angle as there is between triangle and triangle, and the proportion of triangle to triangle is the same as that of gravity to gravity [the same as those] in which the heavy substance is divided in relation to the two cords by which it is suspended; but the proportion is in inverse ratio because the greatest weight falls on the cord which makes itself the outer side of the lesser triangle.

How many are the centres of a heavy body which is not uniform?

There are three centres of a gravity that is uniformly irregular.

Of which the first is the centre of the natural gravity, the second is the centre of the accidental gravity and the third is the centre of the magnitude of this heavy body.

But the centre of the natural gravity does not lie within the position of equilibrium if the heavy body is not uniform in weight and of suitable shape, such as the spherical or parallel body or others like these.

E 68 v.

OF THE THINGS WHICH DESCEND IN THE AIR

The air becomes condensed before bodies that penetrate it swiftly, acquiring so much more or less density as the speed is more violent or less.

A plank that is uniform in breadth, length, depth and weight will not preserve the slanting movement with which it started through the air that it penetrates for a long space, but will turn back and then again forward and so end its descent with a fluctuating movement. This springs from the fact that the uniform natural thickness of the air is destroyed because it is condensed under the right angle of the surface which strikes the air and cleaves it open. But on the opposite face of this plank it does the contrary in that it becomes rarefied, and as a consequence the rarefied air is of less resistance, and for this reason this surface shows itself heavier. The rarefaction acquired by the air that is behind this plank is much greater than the density that is produced in front of it. It may be proved why the air is condensed: — the air is condensed before the bodies that penetrate it for when one pushes a part one

does not push the whole of that which is in front. This is demonstrated by the flooding that is produced before the prow of a ship. E 70 V.

[*Of the descent of heavy bodies in the air*]

Conception

The air becomes as much more rarefied behind the movement of the movable thing as it becomes denser in front of the same movable thing.

Why the slanting descent does not keep its straightness.

The straight line of the oblique descent made by bodies of uniform thickness and weight in air of equal resistance will not be continued by a heavy substance that descends. And this is due to the fact of the air being pressed by the surface of the heavy substance that is penetrating it, and becoming condensed resisting and stopping this surface; whence of necessity the opposite surface of this heavy substance finding itself in rarefied air immediately acquires gravity and falls with more speed than that which is retarded by the thickness of the air condensed by it. And for this reason the impetus to the right made by the movable thing is turned to the left, preserving its slant, up to the point at which the other air is condensed anew beneath it; this air again resists and again turns the left slanting descent to a right descent, then from right to left and from left to right until the point at which the movement ends.

The descent of the beam placed in any slanting position will always be made by a straight line. This is proved by the seventh of this which says:—'Heavy substances of uniform shape and weight which descend through an equal medium will have the same rate of speed'. If therefore a beam of uniform shape and weight be divided into equal and similar parts their descent will be of equal and similar speed, and what the part does the whole will do.

The adversary says that the whole beam united will not have a descent similar to the descent of its divided parts because the whole gives the whole of its weight slanting to the lower surface, and the part gives the whole of its weight to the surface of the part and there is such speed from surface to surface as there is from the whole to the part.

E 73 r.

OF BODIES NOT UNIFORM IN SHAPE

Of heavy substances not uniform in shape the heavier part will always become the guide of their descent through the air.

With beams of uniform shape at the end of the movement the

movable thing will have always preserved the same slanting position that it had at the beginning of the movement.

This is proved by means of the beam suspended on the balance *n m*.

The heavy substance weighs so much less in the air as its movement is more slanting.

And the straight descent of the beam weighs as much less in the air as this beam is less slanting.

E 73 v.

OF THINGS THAT DESCEND IN THE AIR

A heavy substance of uniform thickness and weight, placed in a position of equilibrium will have a straight descent with equal height in each of its parts without ever deviating from the position of its first equilibrium, if the air be motionless and of uniform resistance, and this movement will be very slow as will be proved.

But if the heavy substance of uniform thickness be situated slantwise in air of uniform resistance then its descent will be made slantwise and it will be more rapid than the first aforesaid.

E 74 r.

OF THE WEIGHING OF LIQUIDS

[*Figure*]

The balance *a e g* is formed of two tubes joined at an angle in the lower part, and the water that is enclosed within them is joined having in the one arm a quantity of oil and in the other plain water.

I say that the level of the water in one tube and the other will not remain in a position of equality, nor will the surface of the oil find itself in a position of equality with the surface of the water placed in the opposite tube. This is proved because the oil is less heavy than the water and for this reason it remains above the water, and its heaviness united in the same tube with the heaviness of the water that lies beneath it makes itself equal to the weight of the water that is united to it as a counterweight in the opposite tube. But since it is said that oil is less heavy than water it is necessary, if one should desire to create an equivalent to the weight of the water that is lacking beneath it, that there should be a greater quantity than of this water that is lacking, and that as a consequence it occupies more space in this tube than an equivalent weight of water would have occupied; and therefore the surface of the oil in its tube is higher than the surface of the water in the

opposite tube, and the surface of the water that is beneath the oil is lower than the surface of the water opposite. E 74 v.

OF THE DESCENT OF HEAVY BODIES

Of heavy bodies which are not flexible and are of equal weight one with another, there will be the same proportion between the speed of their descent as is that of their uniform bulk.

Whether the air which clothes bodies with itself moves together with these bodies.

The air that clothes bodies with itself moves together with these bodies: this experience shows us when the horse runs along dusty roads.

Whether the movement of the air is as swift as its mover.

The air will never have swiftness equal to that of its mover; and this is shown us by the movements of the dust that I have already mentioned which follows the course of the horse, for after having moved a very short distance it turns back with an eddying movement and thereby consumes its impetus. E 80 r.

[*Of movement*]

First: If a power move a body through a certain space in a certain time the same power will move the half the body in the same time twice the space. Second: Or the same virtue will move the half of this body through this whole space in half this time. Third (as Second). Fourth: And the half of this virtue will move the half of this body through all this space in the same time. Fifth: And this virtue will move twice this movable body through the whole of this space in twice this time, and a thousand times this movable body through the whole of this space in a thousand such periods of time. Sixth: And the half of this virtue will move this whole body through half of this space in this whole time, and a hundred times this body through the hundredth part of this space in the same time. Seventh: And if separate virtues move two separate movable things through a given space in a given time, the same virtues united will move the same bodies united through this same space in this same time, because in this case the first proportions remain always the same. F 26 r.

OF THE MOVEMENT OF THE AIR ENCLOSED BENEATH THE WATER

Whether the air escapes from beneath the water by its nature or through its being pressed and driven by the water.

The reply is that since a heavy substance cannot be supported by a light one this heavy substance will proceed to fall and seek what may support it, because every natural action seeks to be at rest; consequently that water which surrounds this air above, on the sides and below finds itself all spread against the air enclosed by it, and all that which is above *d e n m*, pushes this air downwards, and would keep it below itself if it were not that the laterals *a b e f* and *a b c d* which surround this air and rest upon its sides came to be a more preponderant weight than the water which is above it; consequently this air escapes by the angles *n m* either on one side or on the other, and goes winding as it rises.

As much force is exerted when an object is moved against the motionless air as when the air is moved against a motionless object.

I have seen movements of the air so violent as to carry away and strew in their course immense forest trees and whole roofs of great palaces; and I have seen this same fury with its whirling movement bore a hole in and hollow out a bank of shingle and carry away in the air gravel, sand and water for more than half a mile.

The same weight will be sustained in the air without movement, if falling there with slanting movement, it is able afterwards to raise itself up very high with a reflex movement.

F 37 v.

How much air is required to raise various heavy objects of different material?

How much water entering into the boat will cause it to sink?

Which air supports more [?less]? That enclosed or rarefied as in the case in cupping glasses? Or in its natural state? Or when compressed, as it is in balls which are inflated by the force of a screw? There can be no doubt that it is the rarefied, then that in its natural state, and the compressed air resists least [?most].

Each part of the volume of the water which falls from the river through the air follows the line in which the impetus was commenced which led it to this fall.

F 47 v.

[*Movement of liquids*]

The natural movements of liquids in the air are swifter and more diffused at the end than at the beginning.

The semi-natural movements made by the water between the bed of the river and the air will be of equal speed if the bed of this river is straight and equal in slant and breadth.

The accidental movements made within the air become slower at every stage of height.

The semi-accidental movements made between the bed of the canal and the air upon a bed of uniform slant and width always tend to become slower, but are longer than the simple-accidental because they proceed to support themselves and always lighten themselves of part of their weight.

F 50 V.

First. If a power move a body a certain space in a certain time the same power will move the half of this body in the same time twice this space.

Second. If any force move any movable thing through a certain space in a certain time the same force will move the half of this movable thing through the whole of this space in half this time.

Third. If a force move a body in a certain time a certain space the same force will move the half of this body in the same time the half of this space.

[Fourth?] If a force move a body in a certain time a certain space it is not necessary that this power move twice this weight in twice the time twice this space, because it might be that this force would not be sufficient to move this movable thing.

[Fifth?] If a force move a body in a particular time a particular space it is not necessary that the half of this force move this same movable body in the same time the half of this space for perhaps it would not be able to move it.

Sixth. If two separate forces move two separate movable things the same forces united will move in the same time the two movable things joined together for the same space because there remains still the same proportion.

F 51 V.

Fourth. If a power move a body in a particular time a particular space half the force will move in the same time half the movable thing half this space.

If every movable thing pursues its movement along the line of its commencement what is it that causes the movement of the arrow or thunderbolt to swerve and bend in so many directions whilst still in the air?

What has been said may spring from two causes one of which is that the air which is compressed before the fury of its onset offers resistance to it, and consequently this movement becomes bent and assumes the nature of a reflex movement though it does not proceed in straight lines. Its action is as in the third of the fifth concerning water, where it is shown how sometimes the air issuing out of the beds of the swamps in the form of bubbles comes to the surface of the water with sinuous curving movement. The second manner of sinuous movement of the flash of lightning may arise from the fact that the substance of the thunderbolt discharges itself now to the right and now to the left, now upwards and now downwards, acting in the same way as the spark that leaps from the lighted coal; for if the coal exhales gas from one of its sides it becomes disintegrated by the damp spreading within it and bursting into flame separates these pieces of coal and produces another spark, which at its birth strikes against the rest and drives it back; and this then does the same again in different directions throwing out a succession of sparks into the air until it is itself consumed. But to me the first explanation pleases most because if the second were true you would see that a single thunderbolt would produce many just as this spark does.

F 52 r.

CONCERNING THE LOCAL MOVEMENT OF FLEXIBLE DRY THINGS SUCH AS DUST AND THE LIKE

I say that when a table is struck in different places the dust that is upon it is reduced to various shapes of mounds and tiny hillocks — and this arises from . . .

The dust which when the table is struck is divided into various hillocks descends from the hypotenuse of these hillocks, enters beneath their base and raises itself again round the axis of the point of the hillock, and so moves as to seem a right-angled triangle; and this arises from . . .

When the dusty table is struck at one side observe the manner in which the movement of the dust commences to create the aforesaid hillocks, and how this dust rises to the top of the hillock.

F 61 r.

MOVABLE THINGS IN THE AIR

The movement of the air is less in front of the movable thing that penetrates through it than it is behind this movable thing.

The air that fills the void which the movable thing leaves of itself

as it penetrates through this air has its whole mass of equal speed to that possessed by this movable thing; but the parts of this air because it is of the nature of a vortex, that is with circling movement in the form of eddies, is much swifter in itself than the movement of the aforesaid movable thing.

Here it seems that because the movable thing has more swiftness of air behind it than in front this air is the cause of the movement of this movable thing, and by the seventh this cannot be.

No movable thing is ever swifter than the swiftness of the power which moves it.

The wave that the air makes before the movable thing which penetrates it does not pass almost in front of this movable thing, because this would be contrary to the seventh, the last but one.

The air behind the movable thing turns back revolving in those parts which border on that which flows behind the movable thing.

The air that flows behind the movable thing which wanders through it is moved by the impetus afforded it by this movable thing; and striking with its great expanding wave upon the other air it turns back, and with a great revolving movement which grows less at its extremities it finally comes to stop and does not follow this movable thing. F 74 r.

WHY THE MOVABLE THING FOLLOWS THE MOVEMENT COMMENCED BY ITS MOVER

No impulse can end immediately but proceeds to consume itself through stages of movement.

The air which was at first behind the hole made by the movable thing in the air accompanies this movable thing only a little way, according to the eighth.

Eighth. The air which successively surrounds the movable thing that is moving through it makes divers movements in itself. This is seen in the atoms that are found in the sphere of the sun when they penetrate through some window into a dark place. If among these atoms one throws a stone in the length of the solar ray one sees the atoms range themselves about the position where the course taken in this air by the movable thing was filled by the air, as is proved in the fifth.

Fifth. Nothing that is not provided with power of sensation moves of itself, but its movement is made by others; and the movement produced

acts very briefly in the time and in the space that necessity gives, *as is shown in the fourth.*[1]

Fourth. The air which moves to fill up the vacuum made in it by the movable thing has in itself varying degrees of speed density and movement. F 74 v.

Every movable thing that creates a reflex action ends its course in the line of its incidence.

This happens because the movement of its incidence is of greater power than the reflex movement and that which is more powerful has more duration than the less powerful.

The movement of incidence of the movable thing will be more powerful than its reflex movement, because the percussion of the incidence made upon the dense object diminishes in part the impetus united to this movable object, and this diminution does not leave this reflex movement as powerful as it has been said the movement of incidence is. In every stage of movement however the impetus of the movable thing is diminished of itself apart from its percussion with a dense object, and it does not follow that this percussion will not lessen it much more, seeing that if you measure the movement which this movable thing would have made without incidence and the movements produced by many bounds up and down, you will find that the continuous movement in the same spot will be longer than that which is frequently broken by the incidences, even though the beginnings of the impetus in each of them were of equal power one with another. F 75 v.

The more deeply an object is sunk in water the less is it moved by the wind which strikes the part of it that is above the water. This is contrary to Battista Alberti who gives a general rule of how much the wind drives a ship in an hour. F 82 r.

The very rapid friction of two thick bodies produces fire. F 85 v.

An object that has its sides set slantwise in the middle of the course of the water, although the water strikes upon its smooth side, will go in greater bulk towards the side of the slant that is lower.

OF THE AIR

And because as is proved in the seventh, it is not alien to the nature of the air to become compressed and rarefied almost in a moment,— and

[1] Words crossed out in MS.

this is not found possible with water, which keeps its first form,— it is therefore easier for the air at the side of and above the movable thing to descend there in order to fill the vacuum of itself left by this movable thing above itself, than for the air beneath to bend and move in a long curving line in order to fill up this vacuum; and this is also impossible by the eighth, which proves that every impetus moves this air with it along the line in which this impetus is created, as the wind which moves as much air as its impetus moves, as is seen with the dust stirred by these winds or with the atoms floating in the sun's rays when they are blown about by it. So therefore the air, being driven by the impetus of the heavy substance which descends there, flies by the line of the movement made by its mover, that at the side becomes changed into lateral eddies, and the upper air descends there from above, always filling up the vacuum that the movable thing leaves above of itself at each stage of its movement.

The air below the movable thing which descends through it becomes dense and above it becomes rarefied.

F 87 r.

The movement that the air makes in the air compresses itself and the air that it strikes.

Air moved in a body that is thicker than itself compresses itself more than when it moves in other air.

Air moved within a body lighter than itself becomes rarefied.

Water moved within a body lighter than itself comes to be rarefied not in its quality but in the quantity of its dispersion and extension.

F 88 r.

Of the proportion that the movement of water has which is poured out of the bottom of a very long trench, the exit of which is a hundred times narrower than the breadth and depth of the trench:

It may be asked how much slower will be the movement of the water in the upper part of the trench than the movement of the 'rozza' which is formed of the same breadth as the mouth by which the water issues from the trench.

F 95 r.

I have learnt from percussion that the falling movement exceeds the reflex movement.

G 1 r.

OF THE SCIENCE OF WEIGHTS [*with diagram*]

The heavy object which descends freely does not give its weight to any support. This may be proved: *a* is one and *b* is two; it follows that *m* supports only two because the excess that *b* which is two has over one is one. And this one finding no resistance in *a* descends freely, for it has no support and not having any support does not have its movement impeded. Therefore *m* the extremity of the balance is not sensible of this excess because that which falls is not supported.

G 13 V.

OF THE NATURE OF THE CORDS PLACED IN THE TACKLES

The cords of the tackles will be broken in the contact of the cord of the motive power with the first pulley. This is proved by the ninth of this which says: 'The cords in the tackles which descend always undergo greater strain than those that rise'. And 'Of the cords that descend the last feels less of the force of the motive power than the first'. And 'The cords of the tackles feel more weight in proportion as they are swifter: of the cords that move within the tackles the last is swifter than any of the others.'

QUESTION OF THE WEIGHTS DESCENDING

The question is whether the weights descending in the pulleys give more or less of their weight to the pivots of the tackles as they descend than when they are stationary.

G 17 V.

OF THE DIFFERENCES THAT THERE ARE BETWEEN FORCE AND WEIGHT, AND FIRST OF FORCE

Of the spring and counterpoise of equal powers it is always the spring which is worth more, seeing that its power is pyramidal; and its greatest power is at the commencement of its movement. But the counterpoise has a compound power, one part of which is cylindrical and the other pyramidal. The cylindrical is such that the weight is always equal in itself and draws with an equal power both at the beginning of the movement and at the end. But the pyramidal commences in an instant and at a point, and with each degree of movement and of time it acquires volume and speed, its movement being free and swift. But in the slow movement made by the heavy substance the pyramidal power ceases and there only remains the cylindrical power, which as has been

said is worth at the beginning as much as it may be worth at the middle or at the end or in any other part of its movement.

G 30 r.

CONCERNING WEIGHTS

If the angle formed by the meeting of two slanting cords which descend to the point of suspension of a heavy body is divided by the centre line of the heavy body, this angle is divided into two parts which will have the same proportion between them as that in which the said heavy body is divided within the two cords.

If the angle formed by the meeting of the two cords that descend to the point of suspension of a heavy body is divided by the intercentric line which passes through this heavy body, this angle is then divided into two other angles, between which there is the same proportion as that from base to base and from angle to angle, and equally from whole triangle to whole triangle; and these proportions resemble those of the weights which the heavy body gives of itself to its supports.

G 39 v.

The staff most uniform in thickness bends with the most perfect curve.

G 45 r.

OF THE MOVEMENT OF SHIPS [*Drawings*] *b a*, *d c*, *f e*

These three ships of uniform breadth, length and depth when propelled by equal powers will have different speed of movement; for the ship that presents its widest part in front is swifter, and it resembles the shape of birds and fishes such as the mullet. And this ship opens with its side and in front of it a great quantity of water, which afterwards with its revolutions presses against the last two thirds of the ship. The ship *d c* does the opposite, and *f e* has a movement midway between the two aforesaid.

G 50 v.

OF A MOVABLE THING NOT OF UNIFORM WEIGHT MOVING IN AIR OR WATER

In movable things uniform in substance but not of uniform weight the heaviest part always serves as a guide.

The pyramidal weight uniformly irregular in size which is pushed by the bow with the point forward will turn its base immediately towards the place where the whole is moved.

G 51 r.

OF THE MOVEMENT OF THE MOVABLE THING

An arrow shot from the prow of a ship in the direction in which the ship is moving will not appear to stir from the place at which it was shot if the ship's movement be equal to that of the arrow.

But if the arrow from such a ship be shot in the direction from whence it is going away with the above-mentioned rate of speed this arrow will be separated from the ship with twice its movement.

G 54 r.

Of the movement of the movable thing which glides with continuous movement over a movable spot or which being movable flows away.

The movement of the liquid which flows through the bottom of the movable vessel will be in a straight line situated slantwise, the slant being at a greater or less angle according as the movement of the vessel is swifter or slower.

Of the movement made by the place that receives the thing poured out from the vessel.

There is as much force necessary to receive upon the moving place the thing which is poured from the immovable vessel as there is to move the vessel which causes the thing to pour upon an immovable place.

But if the movement of the vessel that pours equals the movement of the place which receives upon it the thing that is poured the movement of the thing that descends is a slanting straight line, as is shown above.

OF THE MOVEMENT OF THE ARROW DRIVEN BY THE BOW

The arrow shot from the centre of the earth to the highest part of the elements will ascend and descend by the same straight line although the elements may be in a movement of circumvolution round their centre.

The gravity which descends through the elements when they are in circumvolution always has its movement to correspond to the direction of the line that extends from the commencing point of the movement towards the centre of the world.

G 54 v.

OF THE MOVEMENT OF THE MOVABLE THING

Of the heavy substance descending through the air, the elements that revolve making their entire revolution in twenty-four hours:

The moving substance that descends from the uppermost part of the

sphere of fire will make a straight movement as far as the earth although the elements are in perpetual revolving movement round the centre of the world. This is proved: — let *b* be the heavy substance which descends through the elements which moves from *a* to descend to the centre of the world *m*; I say that such heavy substance, although it may make a curved descent in the form of a spiral line, will never deviate from its rectilinear descent by which it advances continually between the place from whence it is separated and the centre of the world; for if it were parted from the point *a* and descended to *b*, during the time in which it has descended to *b* it has been carried to *d*, the position of the *a* has become changed to *c*, and so the movable thing finds itself in the [line of] direction that extends between *c* and the centre of the world *m*. If the movable thing descends from *d* to *f*, the beginning of the movement moves in the same time from *c* to *f*, and if *f* descends to *h* it turns at *g*, and so in twenty-four hours the movable thing drops to the earth below the place from which it was first separated, and such a movement is composite.

If the movable thing descends from the highest to the lowest part of the elements in twenty-four hours its movement is formed of straight and curve. I say straight because it will never deviate from the very short line which extends from the place from which it is separated to the centre of the elements, and it will stop at the lowest extremity of such line of direction, which is always found according to the zenith beneath the place from whence this movable thing is separated. And this movement is curved in itself in all the parts of the line and as a consequence at the end it is curved in all the line. And from this it comes about that the stone thrown from a tower does not strike the side of the tower before reaching the ground.

G 55 r.

OF SIMPLE IMPETUS

Simple impetus is that which moves the arrow or the dart through the air.

Compound impetus is that which moves the stone when it issues from the sling, and this impetus is not of long duration because the noise produced by the revolving movement of the movable thing reveals to us that this movable thing meets with resistance in the air that it penetrates.

G 72 v.

OF IMPETUS

Impetus is the impression of movement transmitted by the mover to the movable thing.

Impetus is a power impressed by the mover on the movable thing.

Every impression tends to permanence or desires permanence.

This is proved in the impression made by the sun in the eye of the spectator and in the impression of the sound made by the clapper as it strikes the bell.

Every impression desires permanence as is shown by the image of the movement impressed upon the movable thing.

G 73 r.

OF PERCUSSION

The air that is compressed beneath the movable thing as it descends through it in a slanting position flees more from the upper than from the lower part of this movable thing.

Continuous tracts of air are as much rarefied on the one side as they are compressed on the other.

The rarefied part of the air offers so much less resistance as the compressed part offers more resistance. Therefore the back part of the movable thing, *b*, will descend with greater impetus than its front part, and this is the reason why the front *a* which at the outset was below, at the end of the reflex movement is raised up.

G 73 v.

OF THE DESCENT OF THE HEAVY BODY

Every natural action is made in the shortest way: this is why the free descent of the heavy body is made towards the centre of the world because it is the shortest space between the movable thing and the lowest depth of the universe.

G 75 r.

OF WEIGHT

Every heavy substance when it moves horizontally has only weight in the line of its movement. This is shown by the first part of the movement made by the ball from a mortar, this movement being in a horizontal direction.

But the heavy substance floating in the wind in any direction will have so much more or less gravity round the front than in the beam of the balance, according as the junction of the pendulum of the weight with the arm of the balance is nearer to a right angle.

The revolving movement made rapidly by the weight round the fixed point of its axis will have so much more heaviness in this weight as this revolving movement is more rapid.

G 77 r.

OF THE WEIGHT OF THE BEAM OF THE BALANCE

The weight that the beam of the balance has is divided in two parts, of which one tends towards the centre of the world and the other is accidental, because it moves by transverse movement. But the first, which casts its weight towards the centre of the world, has equal lateral weights on either side, and these fix in accordance with their centres of gravity and their distances the mathematical centre of this balance. The second mathematical centre may rather be termed the point of mathematical contact of the pole of the balance with its support, and this is away from the centre of the natural gravity of the balance by as much space as the upper part of this balance exceeds the lower part in weight; for which reason the transverse weight of this balance does not of itself give weight to either of the two above-mentioned centres; and this is proved in the sixth of this which says:—'Every parallel body of uniform thickness and weight placed slantwise has in it two divided gravities of which the one tends towards the centre of the world and the other is transverse.' But the one is natural and simple and the other accidental and compound.

But if such body situated in such a way has a free descent in the air the centres of the two gravities will become transformed one into the other during some period of movement; and at the end there will remain one single centre common to all the heavy substance that descends; and thus with straight movement it will penetrate all the air that is below it.

G 79 v.

WHAT IS IMPETUS

Impetus is that which under another name is termed derived movement, which arises out of primary movement, that is to say when the movable thing is joined to its mover.

In no part of the derived movement will one ever find a velocity equal to that of the primary movement. This is proved, because at every stage of movement as with the cord of the bow there is a loss of the acquired power which has been communicated to it by its mover. And because every effect partakes of its cause the derived movement of the arrow goes lessening its power by degrees, and thus participates in the power of the bow which as it was produced by degrees is so destroyed.

HORSE AND RIDER IN RAPID MOVEMENT

Royal Library, Windsor

The impetus impressed by the mover on the movable thing is infused in all the united parts of this movable thing.

And this is shown because all the parts both those internal and those of the surface are of equal movement except as regards the movement of circumvolution, for in this the more impetuous part always revolves round the less impetuous, that is those which are nearer the centre of the movable thing. And the part that was first moved always remains more distant from the beginning of its movement if it is not checked, and this is admitted because it is more potent in its capacity to revolve.

And if one were to say with the adversary that the impetus which moves the movable thing is in the air that surrounds it from the middle backwards, one would deny this, because the air that follows the movable thing is drawn by the movable thing to fill the void left by it, and because also the air that is compressed before the movable thing escapes backwards in the opposite direction.

And if the air turns back it is a manifest proof that it strikes against that which the movable thing draws behind it; and when two things collide the reflex movement of each starts, and these reflex movements are converted into whirling movements which are carried by the air that fills up the vacuum left by the movable body, and it is impossible for the movement of the mover to be increased by the movement of the movable body in the same time, because the mover is always more powerful than the movable thing.

G 85 V.

OF MOVEMENT AND OF THE MOVABLE THING

Which will remove the same movable thing a farther distance, a great power with a small movement or a lesser power with a greater movement?

The derived movement made by the same movable thing will be of greater length which has a greater primary movement from the same mover.

This is proved because experience shows us that the same power always has such proportion between its primary movement and the derived movement of its movable thing which . . .

It is proved by the fifth of this which says: — between the various lengths of the primary movement one will find that the various lengths of the derived movement of the same movable thing are in the same proportions as their primary movements, because if the power of the same mover separates the movable thing from itself a space of a finger in one

interval of harmonic time, the same power in two intervals of harmonic time will separate the same movable thing twice the same finger's space from itself. And this arises from the fact that the derived movement always has the same proportion as the primary movement.

The impetus is not always produced in the movable thing because not even the mover has always an impetuous movement.

As is shown by the light chariot drawn by oxen over a level tract, for so soon as the oxen end their movement the movement of the chariot is ended.

G 86 r.

OF THE FIVE DIRECTIONS OF MOVEMENT

There are five varieties of local movements of which the first is upwards, the second downwards, the third in a horizontal direction, the fourth slanting upwards and the fifth and last slanting downwards.

How the impetus of movable things joined by a cord passes from one movable thing to the other.

The impetus produced by the movable things joined with a cord each of which is reciprocally the mover, of the other will remove the two movable things to a short distance from their first mover.

When of two movable things joined by their two opposite extremities to the same cord the one is less than the other, the sum of their movement will be less than if these movements were equal to each other.

When the larger of two weights joined to a cord is first in movement, the movement of the two joined together will be greater than if the beginning of the movement had originated with the lesser movable thing.

G 86 v.

WHAT IS PRIMARY MOVEMENT

Primary movement is that which is made by the movable thing during the time when it is joined to its mover.

OF DERIVED MOVEMENT

Derived movement is that which the movable thing makes in the air after it is separated from its mover.

Derived movement has its origin in primary movement and it never has swiftness or power equal to the swiftness or power of the said primary movement.

The course of this movable thing will be in conformity with the direction of the course of its mover when all the parts of this movable thing have movement equal to the primary movement of their mover.

If all the parts of the movement made by the part of one whole are of equal movement then this movable thing will not revolve; and this movement will receive the whole power of its mover, and it will observe the proper length that its movement requires, the weight of the movable thing being proportioned to the power of its mover. G 87 r.

OF TACKLE

The ropes of the tackle share in equal parts the weight that they support.

The power that moves the tackle is pyramidal since it proceeds to delay with uniform lack of uniformity down to the last rope.

And the movement of the ropes of this tackle is pyramidal because it proceeds to delay with uniform lack of uniformity from the first cord to the last.

Therefore the rope feels the power of the mover so much more when it is swifter and so much less when it is slower.

The ropes feel the power of their mover so much the more when they are nearer and so much less when they are farther away. G 87 v.

OF POWER

The same virtue is so much more powerful as it is more concentrated.

This is the case with heat, percussion, weight, force and many other things. And let us speak first of the heat of the sun which imprints itself in a concave mirror and is reflected by it in pyramidal figure, which pyramid acquires proportionately so much more power as it is more constricted. That is that if the pyramid strikes the object with half its length it contracts half its thickness at its foot; and if it strikes it at ninety-nine hundredths of its length it contracts its base by ninety-nine hundredths and increases by ninety-nine hundredths the heat which this base receives from the above-mentioned heat of the sun or of the fire.

Furthermore the percussion of the pyramidal iron will penetrate the penetrable thing struck by its point to a greater extent according as this point is narrower.

The heavy substance also when constricted in less space is of greater weight because a less quantity of air offers resistance to it. Of movement and force we shall speak elsewhere.

So also such other qualities as sweetness, bitterness, sharpness, roughness do the same as has been stated above; and an example of this is shown when any of these increases in quantity mixing itself with snow or water which neither gives it flavour nor takes it away from it but completely deprives it of power.

G 89 v.

The greatest strength of the tackle is in the rope that is joined to its moving power. And the least strength will be in the rope that is joined to one of the tackles.

The weight drawn by the ropes that pass through the tackles is divided in equal parts between the ropes joined to these tackles.

That rope of the tackles will be swifter which is nearer to its mover; it follows that the slowest will be that which is farther away from this mover.

G 95 v.

If a man be at the bottom of a well which contains twenty thousand braccia of water he will not be conscious of any weight.

H 49 [1] v.

Why the movement made by the sieve collects together at the top all the lightest parts? And it is the same with the dredger when one searches for gold in the Ticino by means of a blow, and also with the sweepings of the goldsmith's workshop when they are washed.

H 52 [4] v.

If the part of any substance in the air is greater than that in the water its movement will follow the course of the air.

H 59 [11] v.

A straight movement transformed into another without rebound loses its power.

The natural movement will impart the greatest blow which maintains in a straight line the course it has begun.

H 61 [13] r.

Such part of water as is in contact with the air will move according to the course of this air although the water upon the bottom move in a contrary direction.

H 61 [13] v.

Water which descends from a wide expanse by a straight channel will intersect at its entry from right to left.

And after its entry the part in the centre of the channel will be higher than all the rest of the expanse.

In such another course made by the water in its channel the part of the centre will be lower than the rest of the expanse.

As it follows the same space the depression in the centre changes to a greater height.

H 62 [14] r.

The blow is more powerful than the movement and where it is the blow of the water every obstacle is removed: then when the movement is afterwards created it carries with it all the gravity occasioned by the blow and discharges it in the blow made by the rebound, and so from rebound to rebound the force of the violent movement diminishes. Consequently the heaviest of the stones are deposited and not being able to be borne along by the feeble movements which follow they remain there; and the last things which are at the furthest distance from the point at which they started are the lightest things.

H 62 [14] v.

Water that falls nearest the perpendicular has the least power to drive big gravel before it.

H 66 [18] r.

All violent movements grow feebler the more they are separated from their cause.

H 77 [29] v.

In proportion as the natural movement is separated from its cause it becomes more rapid.

H 78 [30] r.

The weight which is at the greatest distance from the perpendicular of its support weighs less.

H 80 [32] v.

That part of the blow produced by a continuing cause will be so much the more powerful as it is more distant from the cause of its movement.

H 81 [33] v.

[*Weight and Water*]

As much weight of water will escape from its position as the sum of the weight that drives this water.

The weight supported on the water will be as great as the sum of the weight of the water which gives place to these weights.

H 92 [44] r.

The centre of every weight rests under the centre of its support.

H 105 [38 v.] r.

OF MOVEMENT AND PERCUSSION

If someone descends from one step to another by jumping from one to the other and then you add together all the forces of the percussions and the weights of these jumps, you will find that they are equal to the entire percussion and weight that such a man would produce if he fell by a perpendicular line from the top to the bottom of the height of this staircase.

Furthermore if this man were to fall from a height, striking stage by stage upon objects which would bend in the manner of a spring, in such a way that the percussion from the one to the other was slight, you will find that at the last part of his descent this man will have his percussion as much diminished by comparison with what it would have been in a free and perpendicular line, as it would be if there were taken from it all the percussions joined together which were given at each stage of the said descent upon the aforesaid springs.

I 14 v.

Pagolo says that no instrument that moves another instrument in contact with it can avoid being moved by it. So if the wheel moves its pinion the pinion will also move this wheel. But such a thing is not general, for though the cog *n* moves the wheel the wheel will not move the cog *n* turned against the ground.

The line of the movement made by the course of two objects that strike which does not bend in meeting with the first object is that which strikes the second object more with its reflex movement; and so that will act conversely which bends more in its impact with the first object.

I 28 r.

That body which when moved strikes the first object with a greater blow consumes more of its impetus in the percussion, with result that the blow made by the reflex movement will be weaker. And the line of the movement which does not bend at all at its first percussion strikes the second object most.

I 28 v.

The leap is always smaller than the descent made by the thing which leaps; and this leap is termed reflex movement, which is always weaker than the straight movement.

I 43 v.

[*The knife-grinder's wheel*]

The pole is worn most on the course in which its mover exerts the

greatest force; as is shown by the knife-grinders who go through the cities.

Every pole becomes worn on the side in which its mover applies most force. See a man sharpening knives by turning a wheel with his feet: as he drives his foot down he starts the force which then produces the movement of an entire revolution. One understands clearly that in proportion as this movement is farther removed from its cause it becomes slower and wears away its support less; and each time that the movement is repeated the pressure of the feet renews it with fresh impetus, and again under this impetus the support is consumed, and so it comes about that the pole is worn unequally.

I 45 r.

[*Movement — falling and reflex*]

I ask whether the movement made by the stone in a continuous line is equal to that movement which is in a reflex line, that is before the rebound and after the rebound.

I 61 [13] r.

OF MOVEMENT

For what reason the mortar does not follow the rule of the carbine: If for a ball that weighs an ounce there be allowed an ounce of powder with which this ball is shot a mile, then the ball constantly increasing in the same substance with each degree of weight, one gives it a proportionate quantity of powder up to a thousand pounds, and increases the size of the machine so that it always takes forty balls, that is to forty times the thickness of this ball, the metal being always half the thickness of this ball; then the carbine increasing in volume in all its particulars from a ball of an ounce to one of a thousand pounds, you will find that the more the ball weighs the farther it travels.

I 84 [36] v.

The movement made by the arm in throwing the stone is twofold; for when the elbow goes forward and the fist with the stone turns back with a circling movement and then goes forward and drops its stone with a sudden stoppage of the arm, this stoppage by its suddenness is followed by a recoil, and produces the effect of percussion in the air; consequently the movement is much greater than if one were to move the arm in one action and it followed a circular movement in leaving the stone.

OF PERCUSSION

Why the short mortar makes a louder explosion when fired than the long one, as one hears it in drawing the breeches of the small cannon.

I 85 [37] r.

The movement made by the cord is much more rapid near the beginning than near the end. Consequently we may say that as the arrow follows the nature of the greatest movement of the power that drives it, when such power diminishes the arrow is already separated from the cord, and the percussion made by the arms of the cross-bow upon the cord that holds it is made after the departure of the arrow, and therefore this percussion does not increase the movement of this arrow.

I 85 [37] v.

MOVEMENT INCREASED BY IMPETUS AND WEIGHT

This movement is at first increased by impetus, because the more the stone which produces it falls the more speed and gravity it acquires; secondly the more the cord that is unrolled from the part of the circle is unrolled the more distant it becomes from the centre of the movement; consequently the more distant it becomes the more it acquires weight and impetus.

I 91 [43] v.

There are some movements of moving things which continue their direction while receiving percussion in the middle of this movement, and these are of great force.

I ask why field-lances or hunting-whips have a greater movement than the arm. I say that this happens because the hand describes a much wider circle as the arm moves than does the elbow; and in consequence moving at the same time the hand covers twice as much space as does the elbow, and therefore it may be said to be of a speed double that of the movement of the elbow and so it sends things when thrown a greater distance from itself.

Thus you see clearly that the circuit described by the elbow is less by half and its speed is slower by half.

It is true that if one takes from the movement made by the hand an amount equal to that made by the elbow they become of equal slowness.

I 99 [51] v.

If the stone moved by the power of its engine follows in the beginning of its movement the greatest power and speed of its mover, why does it not follow this same equality of the first movement without waiting for it to separate as it reduces its speed? If however it should separate immediately what does it profit it to be closely attended by such power?

I 100 [52] r.

The power that moves which accompanies the movable thing farthest will cause it to move farthest from the boundary where it is separated from it.

It is almost universally the case that everything which is the cause of movements decreases its power before it separates itself from the thing moved by it.

The mortar only increases its force because in the longer movement which the ball makes in its body more powder is ignited, for it must needs be admitted that this setting on fire occupies a divisible period of time; and the more periods of time it lasts the more powder is ignited, the more the fire is driven through this machine, and the greater the impetus and fury with which it expels the ball.

One asks with regard to the same course of the mover whether it removes the thing moved farthest if it commences with slow movement and continually increases the impetus, or if it commences quickly and then proceeds to slacken, or if it goes at an even pace.

I 100 [52] v.

I ask whether if two movable things equal in shape weight and substance are of double speed their course will be double the one of the other or no?

Because one sees bows and cross-bows with long arms that have a long and slow range and one sees cross-bows with short thick arms that have a rapid and short range; the percussions of the short make a quick passage in the third part of their movement and the long make a slower one.

In the consideration of this it is necessary to take into account all the mathematical forces; seeing that in the case of these cross-bows there are at work different causes which produce many different effects, for there are found among them some with a great ascent, some with a short one, some long and thin and some fat and short, some wide and some narrow: so they proceed to vary in shape and in power in many different ways.

I 101 [53] r.

MOVEMENT AND WEIGHT. BALLS SHOT FROM MORTARS

To test the residuum of power of the things that move and draw the weights by giving them a greater or a less weight see what is the weight which is most distant from its mover.

And let it always be round in shape and of uniform substance, and the balance *m n* should have its arms of equal length and weight, and the centre of the weight which strikes the centre of the movable weight should be always raised to the . . . . , and moreover when you have found a weight which recedes more from the beginning of the movement going as rapidly as possible by way of percussion and you reproduce it with a simple weight without percussion, you will be able to discern what difference there is between the causes of the movements when they are due to weight and when merely to percussion. And so with regard to this weight you will proceed to change the things that it moves until you find a weight which is proportionate to the power of this mover, that is the ball which is propelled as far as possible from its motive power. Then weigh one movable thing and the other, and consider the distances where they have been moved, and you will be able to deduce with accuracy the general rule between these two powers.

Then diminish the movable thing by half as those agree to do who have written upon proportions, and you will see that it cannot be that the half less weight will be moved twice as quickly by the same power, that is to say that if it was twice as swift it would go twice as far because the proportion of the movements is as that of the speeds. And if some have said that the more the movable thing is diminished the more rapidly its mover drives it in proportion to its diminution on to infinity, constantly acquiring speed of movement; it would follow that an atom would be almost as rapid as thought itself, or as the eye which roves in an instant to the height of the stars; and as a consequence its journey would be infinite, because the thing which can diminish infinitely would increase infinitely in swiftness and traverse an infinite distance, because every continuous quantity is divisible to infinity. This opinion however is condemned by reason and also by experience.

It would follow also that if the mortar throws its ball three miles from itself in twenty divisions of musical or harmonic time with a hundred pounds of powder and a thousand balls, that taking a pound of balls it would make with the said powder . . . in the same time. Work by

the rule of three, saying if a thousand pounds of stone are thrown to me in two divisions of time, you keeping in imagination the three thousand, saying also if a thousand pounds of balls are thrown to me, at the said distance in twenty divisions of time, in how many divisions of time will the same power throw me a pound of balls. And reckon if a thousand give me twenty what will give me one: and you will find that it will give you $\frac{20}{1000}$ divisions of time which make about $\frac{1}{50}$ of time. Now if one shoots with powder the weight of a small grain, the experiment will not send the ball farther than the mortar sends its smoke when one begins to fire, and by this reasoning it would be sent a million miles in the time when the thousand pounds of balls go three miles. You investigators therefore should not trust yourselves to the authors who by employing only their imagination have wished to make themselves interpreters between nature and man, but only [to the guidance] of those who have exercised their intellects not with the signs of nature but with the results of their experiments.

I 102 [54] r. and v., 103 [55] r. and v.

OF MOVEMENT. A MAN JUMPING

The heavier the thing the more power attends its movement.

This is seen with jumpers who have their feet joined, who in order to make a greater jump throw back their clenched hands and then move them forward violently as they take off for the jump, finding that by this movement the jump becomes greater.

And there are many who to increase this jump take two heavy stones in their two hands and use them for the same purpose as they used to use their fists; their leap becomes much greater.

I 104 [56] v.

If a weight falling a distance of ten braccia buries itself a span in the earth how far will it bury itself when it falls two braccia?

I 110 [62] v.

OF MOVEMENT

Albert of Saxony[1] in his 'De Proportione' says that if a power moves a movable thing with a certain speed it will move the half of this movable thing twice as swiftly. This does not appear so to me, for the reason that he does not take into account that this power exerts its ultimate force,

[1] Albert of Saxony, bishop of Halberstadt (14th century), was a commentator of Aristotle.

and unless it did this, the thing which weighed less would not be in proportion to the force of the mover or of the medium through which it has passed. Consequently it would be a thing floating in the wind and not in straight movement, and it would go less far.

I 120 [72] r.

[*Notes*]

I ask in what part of its curving movement will the cause that moves leave the thing moved or movable.

Speak with Pietro Monti of these ways of throwing spears.

I 120 [72] v.

OF MOVEMENT IN GENERAL

What is the cause of movement. What movement is in itself. What it is which is most adapted for movement. What is impetus; what is the cause of impetus, and of the medium in which it is created. What is percussion; what is its cause. What is rebound. What is the curve of straight movement and its cause.

Aristotle, Third of the Physics, and Albertus [Magnus] and Thomas [Aquinas] and the others upon the rebound, in the Seventh of the Physics, 'De Cœlo et Mundo'.

I 130 [82] v.

[*Weight and movement — experiment*]

There are two balls of the same substance and shape but the one double the other in weight, and I wish to let them fall through two tubes so situated that the balls clash together at the end of these tubes. I ask how far each at the beginning of their movement ought to be distant from the meeting of these tubes.

I 131 [83] r.

If the stone or the water struck by the movable thing falling upon it follows the reflex movement in the manner that this movable thing would follow by itself after its percussion or no.

K I v.

A drop that falls upon a place of uniform density and smoothness will in rebounding scatter its extreme particles in an exact circle; and so conversely . . .

K 56 [7] r.

Of movements there are two kinds namely simple and composite.

Of the simple movements none is slower or swifter than the slowness or swiftness of its mover. Composite movements may be either slower

or swifter infinitely more so than their mover; and also they may be equal to this mover.

K 107 [27] r.

In the case of a stick used to beat with, the slowest movement is in the centre of its length.

When one weight falls to the ground at the same time as another weight, in the percussion which they make the lesser weight leaps into the air.

K 107 [27] v.

Nothing movable will ever be swifter than the part of its mover that touches it.

OF THE LEAP OF A MAN

That thing moves more after it is separated from its mover which is moved by a greater power.

K 110 [30] r.

Every small movement made by the movable thing surrounded by air maintains itself as it goes by impetus.

A movable thing moved by a slow mover, if it has to move a thing by rubbing it, only moves when joined to its mover.

K 111 [31] r.

[*With diagrams*]

Why every substance that possesses gravity either free altogether or in part shows in its whole or in part the natural desire to descend.

The wheel *a b* being fixed in the position that you see, the heavy substance *a* will descend at *b*; and below for this reason the heavy substance *c* placed above the centre of its axis, will go as near as it can to the centre of the earth; and *m n* does exactly the same below.

L 40 r.

[*Reflex movements*]

The reflex movement will be of greater strength when it is longer.

And that reflex movement will be longer which is produced between more diverse angles.

The reflex movement which is longer is less impeded because it differs little from the movement of percussion, and this percussion has little strength and consequently it loses little of the power of its first mover.

But if the reflex movement is shorter it is a sign that it is more impeded at the place of the percussion, and it differs much from the

movement of incidence and consequently the power of the first movement is greatly diminished.

L 42 r.

OF PERCUSSION

The reflex movement will be as much weaker as it is shorter.

That reflex movement will be shorter which is caused by a greater percussion.

That percussion will be of greater power which is made between more equal angles.

Of the percussions made between equal angles that will be of the greater strength which is caused against a more compact object.

And in the percussions made on objects of equal compactness that will be more powerful which has its object of greater resistance.

The spherical body turns so much more in the reflex movement as the percussion is made between the more unequal angles.

L 42 v.

[*Movement — cannonball*]

The smoother the surface of the cannonball the greater the ease with which it will turn in the air as it moves.

In a proposition of this kind one imagines that the cannonball shot from the mortar has to turn itself in the air which it compresses, and if this cannonball is not altogether smooth its curve may occasion difficulty in friction with the air which surrounds it, as I have proved in the fourth concerning frictions.

So when the rebound of this cannonball is made at a more obtuse angle this cannonball will turn more upon itself; and if the ball be lacking in smoothness it will come to fail in speed much more than if it was smooth.

L 43 r.

The percussion of each heavy spherical substance will not occasion scars which have between them a proportion resembling that of the slant of the places where they strike.

This proposition would be entirely confirmed by experience if there were not the firm compression of the air driven by the fury of the ball, for this not being of itself swift as is the movement by the mover which drives it becomes compressed, and is the more compressed as it is the more driven. And this is how it comes about that this ball afterwards striking by a line that is not central within the range of the perpendicular [line]

a c commences the first stage of its slant, and the last ends in the range of the horizontal [line] *a b*.

L 43 v. and 44 r.

[*Drawing — ship with sail*]

If the water here were to move as quickly as the air the ship would move like the wind, without a sail; but because the wind is swifter high up than low down therefore the wind has more power on the sail than on the water.

L 47 v.

Corn tossed up with a sieve leaps up in the form of a pyramid.

[*Movement, percussion*]

That thing moves more in derived movement which is more accompanied by its mover.

What difference there is between the percussion of the united thing and that which is disunited.

L 64 v.

[*Weight and movement*]

If the heavier part of bodies makes itself the guide of their movement, and an arrow be pierced and a portion of quicksilver be placed within it, how will the arrow act and what course will it take on being drawn to a height?

If a lance be made up of pieces arranged together after the manner of an indented box why does it deal a harder blow than a lance formed of a single piece?

L 65 v.

RULE OF POWER

If a power move a weight a certain space in a certain time, the half of that power will move that whole body the half of that space in the said time, or all the space in double the time.

Or the whole of that power will move a weight double that first weight half that distance in the same time.

Or it will move the said weight in half the said time half the space.

L 78 v.

Man and every animal undergoes more fatigue in going upwards than downwards, for as he ascends he bears his weight with him and as he descends he simply lets it go.

L 84 v.

That body will show itself heaviest which meets with the most feeble resistance, and that heavy body will meet with the most feeble resistance in which the centre is farthest removed from the centre-line of its support.

L 85 v.

The centre of every gravity that is suspended stands below the central line of the cord that sustains it.

If from the two equal arms of the balance its two cords proceed, the one being double the other in length, as regards the weight and because these cords meet in the same spot in order to support a weight one cord will feel as much more weight than the other as it is longer than the other.

M 37 r.

Gravity suspended to a cord is all in all the length of the cord and all in each of its parts.

M 40 v.

Why the flat sand being made up of grains dissimilar in shape and size the water that flows above it drives these grains with different strengths of movement:

Just as the bodies differing in weight and shape make different movements in the still air so do the air and water which move between bodies at rest. And this is the reason why the sand loses its flatness through the movement of the water that passes over it; for the water that is moved over the sand performs the same function as the air that is moved over the water. And if one should prove that the bottom of the flat sand makes its waves and becomes uneven through the unevenness of its granules, and that this unevenness cannot occur on the surface of the water which is smitten and is of uniform body, I maintain that the air is full of parts which have dissimilar movement and therefore there is no uniformity in the movement of the parts moved by the contact of the air.

M 41 r.

[*Ships — Wind and Sea*]

I ask whether the wave — or rather whether the ship travels as fast as the wave that bears it or as fast as the wind that drives, it or whether it shares in both the one movement and the other.

And if the mariner has the current favourable and the wind contrary I know if they are of equal strength the ship remains in its first position.

M 41 v.

[*Resistance of the air*]

a	*b*	*c*
1	10	9
2	20	18
3	30	27
4	40	36
5	50	45
n	*m*	*s*

The line *c s* represents the movement of the gravity *b m* having taken away the resistance of the air *a n*.

The air when devoid of clouds and mist starts thick at its base and at each degree of its height it acquires in the form of a pyramid degrees of thinness, as is shown by the line *n a*.

And the weight that descends through this air also in each stage of its movement acquires a degree of speed, although I ought first to say that with every degree of time it acquired a degree of movement more than the degree of the time immediately past. This is why I suppose the degrees of the movement to be ten times as powerful as the degrees of the air that resists; consequently we may say that the said ten degrees if one be taken away for the air which offers partial resistance become nine, and the second twenty degrees entering into the denser air has two taken away so that the twenty becomes eighteen, as is shown by the line *b m*.

M 43 r.

[*Of weights moving through the air*]

If two equal weights are situated vertically one below the other and allowed to fall at the same time these in long descent will consume their interval and will come to touch.

When the air is without mist or clouds you will find that at every degree of height it will acquire a corresponding degree of thinness. So also inversely every degree lower down it will acquire a degree of density. And this is why if two equal bodies are placed one below the other a braccio's space apart, that is they are attached by a thread and let fall together in a long movement they will touch because the one below always finds itself in thicker air than the one above it; and besides this the first has the hard work of opening the air and making the waves in it; part of this escapes upwards and charging strikes with its reflex

movement against the second body, but the rest of the air above runs to fill the vacuum which exists behind this body. M 43 v.

Proof of the proportion of the time and movement together with the speed made in the descent of heavy bodies in the shape of a pyramid, because the aforesaid powers are all pyramidal seeing that they commence in nothing and proceed to increase in degrees of arithmetical proportion.

If you cut the pyramid at any stage of its height by a line equidistant to its base, you will find that whatever proportion there be between the height of this section from its base and the whole height of the pyramid, there will be the same proportion between the breadth of this section and the breadth of the whole base. M 44 r.

This happens in the air of uniform thickness.

The heavy body which descends, at each degree of time acquires a degree of movement more than the degree of the time preceding, and similarly a degree of swiftness greater than the degree of the preceding movement. Therefore at each doubled quantity of time the length of the descent is doubled and also the swiftness of the movement.

It is here shown that whatever the proportion that one quantity of time has with another, the one quantity of movement will have the same with the other and similarly one quantity of swiftness. M 44 v.

[*Weight in the air — increase of speed*]

The heavy body which descends freely with every degree of time acquires a degree of movement, and with every degree of movement it acquires a degree of speed.

Although the equal division of the movement of time cannot be indicated by degrees as is the movement made by the bodies, nevertheless the necessity of the case constrains me to make degrees after the manner in which they are made among musicians.[1]

Let us say that in the first degree of time it [i.e. the heavy body] acquires a degree of movement and a degree of speed, in the second degree of time it will acquire two degrees of movement and two of speed and so it continues in succession as has been said above. M 45 r.

[1] Words crossed out in MS.

[*Waves of the air*]

The wave of the air that is produced by means of a body which moves through this air will be considerably swifter than the body that moves it.

What is set forth above happens because as the body of the air is very volatile and moves very easily when a body moves through it it comes to make the first wave in its first movement, and at the same time that wave cannot be produced without it causing another after it and that another. And so this body moving through the air creates beneath it in each stage of time multiplications of waves, which in their flight prepare the path of movement for the movement of their mover.

The wave of the air forming and reforming itself prepares the way of movement for its mover.

The air which is shut up by force becomes heavier than that which is at liberty.

M 45 V.

[*Weight moving through the air*]

The heavy body which has a free descent with every degree of movement acquires a degree of weight.

This arises out of the second of the first which says that 'that body will be heavier which has less resistance'. In this case of free descent of heavy bodies one sees clearly by the example already cited of the wave of the water, that the air makes the same wave beneath the thing which descends, because it finds itself pushed and drawn from the opposite side, that is that it makes a turning wave which helps to drive it down. Now for these reasons the air which flies in front of the weight that drives it shows clearly that it does not resist it and in consequence does not impede this movement; therefore the greater the descent of the wave which travels more rapidly than the heavy body that moves it, the longer the movement of this heavy body continues; and as the last wave becomes more remote the more it prepares the air which touches the weight to a more facile flight.

M 46 R.

[*Density of waves. Weight in the air*]

When waves become divided in minute particles that quantity which above is united and powerful comes to descend to the ground.

Things that fall may be continuous quantities such as staffs, beams and suchlike things, and liquid bodies, although these cease to be continuous when their descent is long.

Others are discontinuous such as stones and other bodies separated the one from the other. Others are neuter as would be the grain from the hopper that turns the mill, sand, and similar quantities of minute bodies of which you may make proof at a great height. And mark what a difference there is between the unity of their exit from the hopper and their density when they arrive at the place of their percussion.

If the air were of uniform thickness at each part of its height the bodies which descend would acquire at each stage of their movement equal degrees of speed.

M 46 v.

[*Weight. Movement. Waves of water*]

Now we have found that the discontinuous quantity when moving acquires at each stage of its movement a degree of speed; and so in each stage of harmonic time they acquire a length of space from each other, and this acquisition is in arithmetical proportion.

How then are we to account for the continuous quantity of liquid bodies in their descent, since in each interval of harmonic time it pours out the same weight and at each stage of movement it becomes longer and thinner, so that in a long course it shows itself ending in a point as does the pyramid; consequently such liquid body would not fall to earth, but it would rather be that each great mass of this body would remain in the air even though it should be a very great river which was continually rolling away; and experience shows the contrary; for as much as departs above strikes at the same time below. And if the same weight of this liquid body makes itself thinner it meets with less resistance from the air and consequently acquires speed; and if by being thinner it has acquired speed this same weight would also for this second reason come to make itself longer and in consequence still thinner and so would descend more rapidly; and this would go on in succession to infinity. Therefore either nature or necessity has brought it about that in whatever manner the descent comes to assume the form of a pyramid, it makes intersection by changing its extremities from right to left and commences to divide itself; and the more it descends the more it divides; and thus with many ramifications it comes to lighten itself and to check its irregular movement.

M 47 r. and v.

[*Weights falling in succession*]

If two bodies of equal weight and the same shape fall one after the

other from the same height in each degree of time the one will be a degree more distant than the other.

M 48 r.

[*Weight. Increase of speed*]

The heavy thing descending freely gains a degree of speed with every stage of movement.

And the part of the movement which is made in each degree of time is always longer successively, the new one than that which preceded it.

It may be clearly shown that what is set forth above is true, for during the same time that the weight *a* descends at *c*, *b* which finds itself fifteen times swifter than *a* has covered fifteen times as much space in its descent.

M 49 r.

[*Balances*]

I wish to make a balance with arms of equal length, of which I wish to make one hanging downwards as is shown in *b c* and which weighs at least four ounces; now I ask how much the arm ought to weigh which is straight and how much larger the one ought to be than the other for it to resist it in a position of equilibrium?

M 51 r.

[*Bodies falling in succession*]

If the descent is made by two bodies equal in shape and weight of which one has commenced its movement before the other the proportion of their percussions will be as that of the length of their movements.

M 52 r.

[*Proportions and projectiles*]

There will be the same proportion of base with base as there is of side with side and height with height.

You will proceed by the rule of three and you will say if the height of the pyramid which I know for certain to be *s c* gives me a braccio for its base; or if a base of a braccio comes from a pyramid of ten braccia, what will another base of sixty five braccia come from?

There arises here an exception, namely that if a ball first goes up a hundred braccia with an ounce of powder it goes through air of greater thickness than would that which rose three thousand braccia, and consequently as that of the said three thousand braccia has been at each hundred braccia in a region of air that is thinner than that before it, it has always acquired more speed.

I wish to know how much higher one small cannon or carbine throws than another, and to do this I train my instrument according to the line *b c* in a firm manner so that it will not alter its angle of elevation. This done, I shall insert so small a quantity of powder that the ball will only be projected two braccia away from the carbine as *b s*, and I shall note where the ball falls, at *n*, then I shall double the charge of powder and see where it falls at *m*; and if I shall find that the base *m c* is double the base *n c* I shall know that the height of the pyramid *h c* is double that of *s c*.

M 53 r.

[*How to lift great weights*]

Great weights ought always to be supported by levers as you see done in order to draw the column out of the barge.

a wedge which of itself supports at *a*.

Wedge. Barge. Windlass.

You will give as many turns with the cord to the column as you wish it to have turns to unroll as you draw it.

M 56 v.

[*Fall of heavy bodies*]

If many bodies of similar weight and shape are allowed to fall one after the other at equal spaces of time the excesses of their intervals will be equal to each other.

Demonstration

By the fifth of the first which says how the thing that descends at every stage of movement acquires equal degrees of speed.

Therefore for this reason the movement of the last downward becomes much more rapid than that of the first from the beginning.

And by the eighth of the first which says that: the upper pair will have in their interval the same proportion with the interval of the lower pair as the speed of the lower pair has to that of the upper pair, and so conversely the speed with the distances will be as the distances with the speed.

The experiment of the aforesaid conclusion as to movement ought to be made in this way, that is that one takes two balls of similar weight and shape and causes them to drop from a considerable height in such a way that at the inception of their movement they touch one another and that whoever is making the experiment stations himself on the ground in order to watch whether at the time of their fall they have remained

touching each other or no. And this experiment should be made many times so that no accident may occur to hinder or falsify this proof — for the experiment might be false whether it deceived the investigator or no.

M 57 r. and v.

OF THE RESISTANCE OF THE AIR

That air will become denser which is pressed upon by a greater weight.

Although *b* is as thick as *a* yet as it is twice as heavy it makes the air which flies below it twice as dense, and as it becomes denser below it becomes proportionately thinner above.

M 58 r.

[*Weight, Percussion, Spring*]

That weight will show itself lighter which has a greater volume.

That weight will make a less percussion which strikes in its descent with a part more distant from the central line of its gravity, or with a part that yields against the object as though it were pressing upon a spring, or with a part which yields against the thing that strikes the object with a spring or which jumps upon the point of its feet.

M 59 r.

[*Falls of heavy bodies*]

Explanation of the movement of the separated quantity.

Why the natural movement of heavy things at each stage of its descent acquires a degree of speed.

And for this reason such movement as it acquires power shows itself of pyramidal shape, because the pyramid acquires similarly in each degree of its length a degree of breadth, and so such proportion of acquisition is found in arithmetical proportion because the parts that exceed are always equal.

M 59 v.

[*Drawing: — two balls*]

These two figures are double in diameter the one of the other and I wish to know how much the one descends more rapidly than the other.

[*Drawing: — two cubes p q*]

Although *p* is eight times *q* nevertheless it is not swifter in its descent than about the double of *q*, which descent will be spoken of here.

Let us say therefore that *q* is three pounds and that the resistance of the air is a pound; consequently the weight which was three becomes

two and consequently of the weight *p* there remains two pounds. So of the four dice below which are three pounds each there remain eight pounds and those above are twelve pounds and this makes twenty containing two ten times and so becoming ten times swifter. M 60 r.

If two balls of equal weight and size are placed at a distance of one braccio one above the other and commence their descent at the same moment, always at each stage of movement the interval between them will be of the same size and will remain as shown at *a b*.

If after the descent of a braccio made by one ball you allow another similar one to fall you will find that at each stage of movement there will be a proportionate change in their speed and force.

It is clearly shown how when the ball has fallen from *a* to *c* it has traversed twice the distance that that ball has which has fallen only from *a* to *b*, and therefore it will be twice as swift and powerful and will bury itself twice as deeply as at *b*, and if when descending or indeed when *a* has descended at *d*, *b* shall find itself at *c*, and the power of *d* will not be more than double that of *c* but will be half as much again. And so when *a* is at *e*, *b* will be at *d* and the power of *d* will be three quarters that of *e*, then four fifths, then six sevenths and so on to infinity. M 60 v. and 61 r.

[*Projectiles*]

OF MOVEMENT

I wish to know what weight ought to be that of lead which will drive a ball of a pound of lead a greater distance from itself than any other weight which is also of lead, the said movers having also the same movement.

And I wish to know how far a weight equal to that of lead being of wood will drive in the same movement from itself the above-mentioned ball of lead.

Among weights of similar shape that will be driven to a greater distance by the same power which finds itself smaller in shape.

THE CONVERSE

Among the weights of like shape which are driven by the same power that which is of greater bulk will be of less movement.

Aristotle says that if a power moves a body a certain distance in a certain time the same power will move half this body twice the distance

in the same time. Therefore the millionth part of this weight will be driven by the same power a million times this distance in the same time; or if this weight was an ounce and it was transported a mile in a period of time the millionth part would be transported a million miles in the same period. And if you were to say that the air would make resistance I maintain that in proportion as this body was less in weight than an ounce the quantity of air would be less that withstood its course.

M 61 v. and 62 r.

[*Movements and proportions*]

Of the movement made by things proportionately to the power which drives them.

One ought to make the experiment with a cross-bow or other power which does not grow weaker, and also with balls of the same shape and of different substances and weights to test which goes farthest away from its motive power, and then to test with various shapes of various sizes breadths and lengths and to make a general rule.

OF THE CONVERSE

I wish to know what weight the power will have which shall drive to a greatest distance from itself a weight of a pound spherical in shape.

M 62 v.

OF THE POWER OF THE CROSS-BOW

The weight that charges the cross-bow has the same proportion to the weight of the arrow as the movement of the arrow of this cross-bow has to the movement of its cord.

Here one ought to deduct three resistances made by the air, that is the percussion of the bow of the cross-bow made upon the air, and that of the cord; the third is that made against the arrow. And as the cord is thicker so its arrow encompasses it the less.

M 63 r.

[*Of wedges*]

Ordinary wedge, immovable because of the mother (madre).

Wedge in sheath of iron for splitting stones.

The force of the wedge is very great because of the percussion, and it acts with marvellous power in dividing the things united and in uniting those divided, in stamping sculptures of metals in bas-relief, in squeezing out the liquids from the places where they are produced, and in drying things that are moist, as well as in many other things as will be shown when

treating of them; although it has the same nature as the screw it surpasses it altogether.

M 63 v.

OF WEDGES THAT ARE PERMANENT

Wedges are of two kinds of which one is called 'permanent' and the other 'transitive'. The permanent is that in which when the wedge has entered it cannot turn back, and the other enters and departs according to the necessity of the case.

The axe and the hammer which comes to be mother (madre) of its handle wishes to be large above and narrow below, and their handles ought to be thick below and narrow above, and then with the permanent wedge one ought to widen it above.

M 64 r.

[*Movements of water and of sand*]

I ask where the water leaves the sand ribbed and where smooth, where thick and where thin, where pure and where mingled with various particles of straw-wood and leaves.

Water falls from its heights and where it makes the greatest percussion it removes the things which are heaviest and fitted for resistance; and after this percussion it carries the heaviest things by the current that is greater and swifter, and so conversely it carries the lighter things in the part of the water that is slower and has less power.

M 64 v.

I ask where the water leaves its muddy banks, where mixed with sand and where thin and fine so that it slips away and where mixed with roots and wisps of straw and leaves.

We shall speak of the cause of the movement that the sand makes upon its bed and what carries it off and how it moves and where and how it stops, and also of the small and large stones and how they group themselves when they stop all together and also of every other thing that goes rolling upon its bed.

M 65 r.

[*Relations of surfaces*]

If two surfaces of different shapes and equal circumferences touch as one is placed upon the other, if that which touches is of like shape and circumference that which does not touch will be of varying shape and of equal circumference.

M 65 v.

[*Movements of water and of sand*]

These waves of the sand are changeable together according to the direction of the river.

The water that is swifter is that which wears away the bed of the rivers most. Hence it comes about how when the sand forms those shells, or after the manner of certain undulations it is seen on the surface of the water, how the sand moved by the greater current of the water becomes more sifted.

How water can flow above by one line and below by another, crosswise; as is shown at *a b* and *c d*.

M 66 r.

Conception. Of everything that moves the space that it acquires is as great as that which it leaves.

Conception. If one thing is removed from contact with another, the extent of the movement which the part opposite to the said contact makes will be as great as the space that is interposed between the parts that at first were touching.

M 66 v.

[*Drawing*]

The way in which the tail of the fish moves in order to drive the fish forward and so also with the eel the snake and the leech.

Conception. If parts of two surfaces touch one another the part of the one that is touched by the other will correspond to that of the other that is touched by the one, or rather there is as much of the first that is touched by the second as there is of the second that touches the first.

M 67 r.

[*With drawing*]

Here contend two forces of water and now one conquers and now the other.

M 67 v.

[*Cross-bow — relation of weight and movement*]

If the cord of the cross-bow draws four hundred pounds weight upon its notch with the movement of a third of a braccio, as it discharges itself it will draw two hundred pounds with two thirds of a braccio distance from its notch, and a hundred pounds will be removed from its position by such power for a space of one braccio and a third.

And so as much as you shall diminish the weight of the movable thing so the power will cause it to make a greater movement, in such a

way that you will always find that the movement of the cord and the movement of the thing moved will be in the same proportion as the weight that drew the cord to the notch was to the weight that was driven by the cord (if the air did not restrain it).

M 71 v.

A bow bends half a braccio and has power of one hundred and pulls two hundred braccia; and another has power of two hundred and opens a quarter of a braccio.

Which will discharge its arrow proportionately farther, the one or the other?

And if another opened a hundred times less and was a hundred times stronger which would carry farthest in proportion with the said arrows?

M 72 r.

RULE OF THE PROPORTION OF REBOUNDS

If you twist the cord *n m* twenty times it will uncoil and make thirty nine revolutions in the contrary direction, and will then roll the opposite way and will make thirty-eight; and so in succession it will go on diminishing in arithmetical proportion until its movement ceases.

The length of the first turn will bear the same proportion to the second as the first right twist has to that of the left.

M 72 v.

[*Risings of water*]

If the reservoir be of uniform breadth and in all the parts of its height so that it touches the water, and from the bottom water issues forth which may be guided upwards somewhat by the edges of its tube, it will spout up in as great force issuing by a narrow tube as by a thick one, because the water as it issues forth in a thin stream is driven by the thin part that is in the reservoir, and the thick part will be guided and driven by the thick part which is likewise in the said reservoir.

M 73 r.

[*Movement and weight. Cross-bow*]

OF MOVEMENT

The length of the movement made by the thing driven by the cross-bow will have the same proportion with the movement of its cord as that of the weight driven to the weight that loads the said cross-bow.

A b is the movement made by the cord of the cross-bow when it is laden and acquires its force.

B c is the contrary movement which the cord makes when it loses

its force, and there is the same proportion between the movement that the cord makes in acquiring force and the movement made by the death of the force, as between the weight driven and the weight that is the creator of the force.

M 73 v.

If a weight moves the cord of the cross-bow as far as its notch, the half of this weight will pass the half of the movement of such cord, and five sevenths of the weight will create three quarters of the movement of the cord towards the notch.

Now in order to give a uniform weight to the movement of the cord which as it slackens diminishes its degrees of force with each degree of movement, you take away the half of the force; thus if it was four hundred in the beginning and in the last stage nothing, take the half of the pyramidal force which was two hundred and calculate with the weight of the arrow.

M 74 r.

OF THE MOVEMENT OF THE ARROW

Although the force of the cross-bow is great at the beginning and nothing in the last stage, nevertheless the movement of the cord through the impetus acquired makes itself swifter towards the end than at the beginning of its movement: wherefore we conclude that the arrow goes to the end of the movement of the cord.

M 74 v.

[*Of the power of percussion*]

Many small blows cause the nail to enter into the wood, but if you join these blows together in one single blow it will have much more power than it had separately in its parts. But if a power of percussion drives a nail entirely into a piece of wood this same power can be divided into ever so many parts, and though the percussion of these occur on the nail for a long time they can never penetrate to any extent in the said wood.

If a ten-pound hammer drives a nail into a piece of wood with one blow, a hammer of one pound will not drive the nail altogether into the wood in ten blows. Nor will a nail that is less than the tenth part [of the first] be buried more deeply by the said hammer of a pound in a single blow although it may be in equal proportions to the first named, because what is lacking is that the hardness of the wood does not diminish the proportion of its resistance, that is that it is as hard as at first.

If you wish to treat of the proportions of the movement of the things that have penetrated into the wood when driven by the power of the blow, you have to consider the nature of the weight that strikes and the place where the thing struck buries itself.

M 83 v. and 84 r.

[*Weight of pyramid*]

If you wish to divide the pyramid in two equal weights divide it lengthwise into four parts and join together the quarter towards the apex and the quarter towards the base; these two parts joined together will be equal in weight and quantity to the two centre parts; that is that one common measure will measure them precisely, as is shown here below.

M 85 v.

[*Movement — cross-bow*]

Of the movement made in such manner that the mover ends its course before the cord remains drawn:

This movement will be of like power to that which is made by the cord which remains drawn when the arrow passes out of the cross-bow, provided that the mover finishes its course in pyramidal power, that is great at the beginning and finishes in nothing. The movement of the arrow however which is great at the beginning and also ends in nothing preserves the length of its power of movement more than the cord does, seeing that its movement was capable of being of the length of four hundred braccia and the movement of the cord which drove this arrow was capable only of a third of a braccio.

[*Diagrams*]

Pyramid of the power and movement of the mover.

Pyramid of the power and movement of the thing moved.

If the cord of the cross-bow after the flight that it has given to the arrow remains curved, it is certain that its power at each degree of movement has acquired degrees of slowness and infinite weakness; consequently we may say such power to be pyramidal because it commences at the base and ends in a point.

The arrow also being driven by the cord of the cross-bow is pyramidal, because at each degree of movement it acquires degrees of slowness and feebleness; but because this pyramid is longer than that of its mover, the arrow has parted from the cord before this cord has stopped; even when its mover was in its greatest power.

M 90 r. and v.

[*Weight and counterpoise. Cross-bow*]

Experiment

Here one ought to experiment upon the same counterpoise and with the same fall of this counterpoise, with different weights of its mover and different shapes, and see first what weight being of spherical shape will be that which will be driven to a greater distance from its mover than any other. In addition to this when you have found what this weight will be, which as I have said is spherical in shape, you will then prove how the weight of this movable thing varies in length and is equipped with feathers after the fashion of an arrow. And further such shape of arrow while of the same weight may be made of different substances heavier or lighter in themselves. And where such a shape stops in proportion to the power of its mover, it may then be tried by experiment whether the movement of its mover is increased if the movement made by the thing moved becomes longer or shorter, although this experiment ought first to be made whilst the movable thing is of spherical shape.

And remember the means which are made use of between the mover and the thing moved, that is the weight of the instrument and the other things.

M 91 r. and v.

[*Movement — Water*]

OF THE MOVER OF STABLE POWER

Water

Here the thing moved can never be less rapid than the movement made by its mover. In effect if the thing moved had movement equal to that of its mover the mover could not make percussion with it, and would only be able to move as much weight as was equal to as much of the water as follows the movement of the wave that drives it.

M 92 r.

[*Counterpoise and cross-bow*]

OF THE MOVER OF POWER CAPABLE OF BEING INCREASED

This movement is the contrary to that of the cross-bow seeing that the mover of this acquires at every stage of movement degrees of impetus, and the cross-bow does the opposite because its cord commences in its force and ends in nothing, whereas the counterpoise as it falls commences in nothing and ends in great power.

Now one understands here that with the great movement that the

cord of the cross-bow makes at the commencement of its movement, the arrow which is moved by this impetus does not slacken its movement at the same time as does that of the cord; on the contrary it follows the quality of the first speed and comes to separate itself from the cord before this cord has finished its movement.

And the thing driven by the counterpoise does the opposite, for as it commences slowly and ends with great impetus it will never be able to separate itself as does the cross-bow, that is to say the thing moved, until such mover has finished its own course.

M 92 v. and 93 r.

[*Cross-bow*]

OF THE MOVER OF DIMINISHING POWER

If a weight of four hundred pounds draws the cord of the cross-bow over the notch the cord has the force of four hundred pounds and as it slackens it ends in nothingness.

And this diminution of force comes about by stages after the manner of a pyramid of which the projecting parts are equal; consequently we may say that the centre of this pyramid is that which may be called the centre of the force, as the nature of its weight acts in the simple staff, in which if one takes its centre one will find the weight of the whole taking in the same way the centre of the rise of the cord of the cross-bow. And measuring the weight which draws the said cord in this position, one will find that this weight is equal to the weight of all the arrows which could be stretched along the length of the movement that the arrow makes when drawn from the notch of the cross-bow on its last course. And if this arrow were long and thin or short and thick or if it was a ball of lead consider how you ought to measure it in the whole route of its course. Think about this and make a general rule for it because it is a matter that requires consideration.

M 93 v. and 94 r.

Excessive force against a like resistance profits the projectile nothing. But if the force of the mover should find itself in proportion to its projectile the movement made by the projectile will be in the first stage of its strength. It is as though I were to attempt to draw a bladder filled with wind against the air; for if this were moved by excessive force the air where it strikes would make such resistance through its becoming compressed that the bladder striking upon it there would leap back just as though it had been driven against a wall. But if this bladder were

moved by a motive power proportionate in force and movement to the lightness of the said projectile, then this projectile will advance as far forward as its power enables it to drive slowly before it the air that withstands its course. B.M. 54 r.

There are two different kinds of percussions, simple and complex. Simple is that made by the movable thing in its falling movement upon its object. Complex is the name given when this first percussion passes beyond the resistance of the object which it strikes first, as in the blow given to the sculptor's chisel which is afterwards transferred to the marble that he is carving. This blow also is divided into two others, namely a simple and a double blow. The simple blow has been sufficiently described: the double is that that occurs when the hammer descends with force in its natural movement and flies back rebounding from the greater blow and then creates an inferior blow and makes this percussion in two places with the two opposite sides of the hammer. And this blow grows less and less in proportion to the number of the obstacles which are interposed between it and the final resistance, just as if someone were to strike a book on its front page when they were all touching, the last page would feel the damage very slightly. B.M. 82 r.

All movements are caused by abundance or dearth, and where there is the greater excess there the movement will be greater. B.M. 132 r.

Movements are of two kinds, of which one is called simple and the other composite. The simple is divided into two parts, and the one is when the body moves round its axis without change of position, as the wheel or millstone or things like these; the second is when the thing moves from its position without any revolution of itself.[1] The composite movement is that which in addition to moving from its position also moves round its axis, as the movement of the wheels of a waggon or other similar things.

Circular movements are of two kinds of which one is called simple and the other composite. B.M. 140 v.

The straightness of the transverse movement continues in the movable thing as long as the whole of the power given to it by its mover continues.

[1] Note in margin, 'progressive movement'.

The straightness fails in the transverse movement because the power which the movable thing acquires from its mover becomes less.

B.M. 147 V.

Force is produced by dearth or profusion. It is the child of material movement, the grandchild of spiritual movement, the mother and source of gravity. This gravity is confined within the element of water and of earth, and this force is infinite, for by means of it infinite worlds could be set in motion if it were possible to make the instruments by which this force could be produced.

Force with material movement and weight with percussion are the four accidental powers in which all the works of mortals have their being and their end.

Force has its origin in spiritual movement which courses through the limbs of sentient animals thickening their muscles, and by this process of thickening the muscles become contracted and so draw back the tendons which are connected with them, and from this originates the force that exists in men's limbs.

The quality and quantity of the force in a man will have the power of giving birth to other force, and this will be proportionately so much the greater according as the movement of the one is longer than that of the other.

B.M. 151 r.

Gravity and force together with material movement and percussion are the four accidental powers by which the human race in its marvellous and varied works seems to reveal itself as a second nature in this world; seeing that by the use of such powers all the visible works of mortals have their existence and their death.

Gravity is a power created by movement which transports one element into another by means of force, and this gravity has as much life as is the effort made by this element to regain its native place.

Force and gravity have much in common in all their powers, differing only in the movements of their birth and death. For simple gravity merely dies, that is as it approaches its centre. But force is born and dies in every movement.

The spirit of the sentient animals moves through the limbs of their bodies, and when it finds that the muscles in those it has entered are responsive, it sets itself to enlarge them; and as soon as they enlarge they shorten and in shortening draw back the tendons which are joined to

them. And from this arises the force and movement of human limbs. Consequently material movement springs from spiritual.

B.M. 151 V.

No element possesses gravity or levity in its natural state. Gravity and levity are caused by one element being drawn into another.

When an equal quantity of elements naturally contiguous have exchanged places they will offer an equal amount of resistance one to another.

B.M. 174 V.

Weight descends for lack of resistance and that resistance which is weak gives way before it more speedily.

B.M. 175 V.

No movement can ever be so slow that a moment of stability is found in it.

That movement is slower which covers less distance in the same time.

That movement is swifter which covers a greater distance in the same time.

Movement can extend to infinite degrees of slowness.

And the power of the movement can extend to infinite degrees of slowness and likewise to infinite degrees of swiftness.

B.M. 176 V.

No element possesses weight within its sphere, and when by chance an element passes over into a lighter one it instantly creates gravity; and not being able to be supported there it falls back again into its own element, and there immediately this gravity dies.

Gravity and force which are interchangeably daughters and mother of motion and sisters of impetus and percussion are always fighting against their cause; and after this has been subdued they conquer themselves and die.

Gravity is a particular action which takes place when one element is drawn into another and not being able to be received there attempts with perpetual combat to return to its own place.

Gravity is a particular fortuitous action of one element when drawn into another; it has as much life as there is desire in these elements to return to their own place.

That which moves towards the centre is termed weight and that

which flies from it is termed lightness; but each is of equal power and life and movement.

B.M. 181 r.

Every heavy body desires to lose its heaviness . . .

Gravity, force, together with percussion, are to be spoken of as producers of movement as well as being produced by it.

Of these three fortuitous powers two have in their birth, their desire and their end one and the same nature.

B.M. 184 v.

Of the things that support themselves without movement in the water no part that is above the water has weight of itself. This is proved as follows: if neither the still water has weight of itself nor the things supported by it, and it is proved by the passage that its weight is wanting and also the weight of the water, how then can we suppose that the motionless water which is without weight should support the weight? And if it supports the bodies it does not support their weight which has been consumed, for this weight is ended with the movement of the penetration which it made in this water.

B.M. 267 v.

When anyone wishes to make a bow carry a very long way he should draw himself right up on one foot raising the other so far from it as to create the necessary balance for his body which is thrown forward on the first foot, and he should not have his arm fully extended; and so that he may be better equipped for the hard work he should fit to the bow a piece of wood which as used in cross-bows should go from the hand to the breast, and when he wishes to discharge the arrow, instantly at the same time he should leap forward and extend the arm that holds the bow and release the cord. And if by dexterity he does all this at the same moment it will travel a very long way.

The reason given for this is as follows:—know that as the leap forward is swift it lends a degree of fury to the arrow, and the extending of the arm because it is swifter lends a second; the driving of the cord being also more swift gives a third. If the other arrows therefore are driven by three degrees of fury and this by the dexterity shown is driven by six it ought to travel double the distance. And I would remind you that you leave the bow relaxed, so that it will spring forward and remain taut.

Forster I 44 r.

CONCERNING WEIGHTS

If there are two men who hold a sheet by its borders in which sheet there is a man who weighs two hundred pounds, and each pulls his end so much that the weight does not touch the ground, know that each of those who are pulling is holding up a weight as great as the man weighs who is in the middle, because he supports half the weight of the man in the centre and half that of the man opposite who is pulling, so it appears that the weight in the centre being two hundred pounds since each of those pulling has two hundred becomes four hundred pounds.

Forster I 48 v.

OF MOVEMENT

Every movement born of movement which is free either divagates or preserves the line of the movement which produces it, except the thunderbolt which descends from the clouds.

For what reason does the club give a greater blow and moves more than the stone?

Forster II 32 r.

If a man with his whole strength throws a stone of four pounds twenty braccia, one of one pound would he throw it eighty (MS. eight) braccia or no? One of half a pound would he throw it one hundred and sixty braccia (MS. pounds) or no? And if he does not throw these to such a distance what is the cause?

Forster II 33 v.

OF WEIGHT

If you should be with your body in a state of precisely equal balance with the opposite counterpoise and you throw your arms up furiously, holding two weights in your hands, I am in doubt whether your weight would become light or heavy: light I said; by the movement made by its extremities it would wish to follow the impetus commenced, wherefore it uproots the weight and seems to lighten the man; also one may say that the air where the arms strike in its resistance may make heaviness after the manner of the jumper who presses down the ground at the beginning of his jump.

Forster II 45 r.

[*Sketch — man mounting pair of steps*]

I ask: this weight of the man at every stage of movement upon this

pair of steps, what weight does it give *a b* and *a c*? Observe its perpendicular under the centre of the gravity of the man. Forster II 45 v.

OF MOVEMENT

Diagram let *a* be sixteen *b* one.

I say that the resistance of the air will not allow the movement to be in the sixteenth proportion, and this experiment may be made upon fine mud of uniform fluidity by dropping two pieces of draw-plate iron into it of sixteen and of one. Forster II 48 v.

A man in running throws less of his weight on his legs than if he is standing still. And in like manner the horse when running is less conscious of the weight of the man whom he is carrying; consequently many look upon it as marvellous that when a horse is in a race it can support itself upon one foot only. Therefore we may say as regards weight in transverse movement that the swifter this is the less it weighs perpendicularly towards the centre [of the earth]. Forster II 50 v.

The wheel as it turns upon its axle causes part of the axle to become lighter and the other heavier even more than double of what it was at first, not being able to move away from its position. Forster II 51 r.

By the law of the balance mathematically an infinite weight is raised. Forster II 53 v.

If the cross-bow or other engine drives a hundred braccia from itself a movable thing of a pound which has one degree of size, how far will it drive a pound of half a degree of size? And then of a quarter and then of an eighth. Forster II 57 v.

CONCERNING MOVEMENT

The centre of the world is indivisible, therefore nothing alone being indivisible the centre is equal to nothing. And if one should make a hole which was with its diameter or indeed its centre the diameter of the world, and there were thrown there a weight, the more it were to move the greater would its weight become.

So having arrived at the centre of the earth which has only the name

and it being itself equal to nothing, the weight thrown would not find any resistance at this centre but would rather pass and then return.

Forster II 59 v.

Every heavy thing which descends freely directs its course to the centre of the world; and that which has most weight descends most rapidly and the more it descends the more it becomes swift.

[*Sketch — ship in water*]

The water that is moved from its place by reason of the ship weighs as much as the actual weight of this ship exactly.

Forster II 65 v.

[*Diagram*]

If two cords support the same weight and are not equal in perpendicular or slant they will not be equally burdened by this weight, but the one will receive so much more of the weight than the other as the one is shorter than the other and as the angles made by the line of the cords and by the beam above to which they are fixed are greater the one than the other.

Forster II 67 v.

OF MOVEMENT

[*Sketches*]

In this circle I wish to experiment in circular movement, that is to place there within things large and small of the same substance, things of equal size of different substances, and keep them mixed or as chance will have it, and see at the end of the movement what position each has chosen.

And I wish to do the same with dust and a blow.

Forster II 68 v.

The ball of the bombard shot through the mist makes a much shorter course and less percussion than that which is shot through the pure thin air; but it will make a considerably louder report.

I believe also that the arrow shot slanting into water twists as does the line of sight; and of this I will make a proof by fixing the bow and shooting in a frame upon which a sheet of paper is stretched, this paper being over the water; and after you have shot on this paper without moving the bow or the sheet of paper take away the water and you will discover the arrow, and by means of a thin line you will be able to discern if the shaft of the cross-bow and the centre of the hole made in

the paper and the length of the arrow are in the same line or no; and by this means you will make your general rule. Forster II 69 v.

If many bodies of equal weight and shape are allowed to drop one after another at equal intervals of time from the same altitude in such a way that there may always be one quantity in the air, I say that the spaces between them will be equal.

If each thing that descends at every stage of movement acquires a stage of speed, we may say: *a* to descend to *b* in six intervals of time, and *b* to *c* in five intervals, and *c* to *d* in four, and *d* to *e* in three, and *e* to *f* in two, and *f* to *g*; and thus the excesses are equal. It is necessary therefore that as many touch the ground as start above with equal time.

Forster II 70 v.

Whatever the proportion of the number of the cords placed in the pulley-blocks which draw the weight to those which sustain this weight, such is that of the weight that moves to that which is moved.

Whatever the proportion of the number of the cords placed in the pulley-blocks, which pass through the pulley-block of the weight, to those which sustain this weight, such is that of the gravity suspended to the weight which sustains it.

As many as are the wheels of the pulley-block, so many times the mover offers resistance of itself and this on one side only. Forster II 72 v.

When the two ends of the cord which go out of the pulley are situated equally the power of the mover will be as that of its resistance.

In proportion as the nature of the positions which the cords assume as they issue from the pulleys displays greater variety of shape, so the power of the mover varies to that of its resistance. Forster II 73 v.

Ascertain always the proportion of the blow in company with the object which has to receive it.

Since one hundred pounds applied at a single blow makes a greater percussion than a million applied one by one, I wish that when you train the battering-ram on the castle you cause the blow to be raised in the air by the simple weight of the men, and then you pull it back after the manner of a catapult or cross-bow, and you will have a good result.

Forster II 74 r.

Prove what the difference is in giving to the arrow blow and movement, or merely blow alone or movement alone as is the custom.

The blow and movement you will give to the middle of the movement usually made by the cord of the cross-bow.

The blow alone you will give to the arrow at the end of the movement of the cord. The movement alone you will give when in all the movement of the cord you always find the arrow.

Forster II 75 r.

Of the screws of equal thickness that will be most difficult which has most grooves upon it.

And among those screws of equal length, thickness and number of ridges, you will find that the easiest to move which has the greatest number of curves of its ridges.

That screw will be strongest to sustain weights of which the ridges have the less number of curves, but it will be most difficult to move.

Forster II 77 v.

The screw will keep a straighter course which is rather drawn than driven; that is it keeps its direction better if you pull than if you press.

If you drive or press with the screw, which touches the thing pressed with the extremity of its curves, this screw being forced will bend on the side opposite to this extremity of its curve which presses.

Forster II 78 r.

I have ten measures of time and ten measures of force and ten measures of movement and ten of weight, and I wish to raise up this weight.

If I double the weight and not the force in the movement it becomes necessary to double the time.

If I double the weight and not the time or the force it becomes necessary to halve the movement.

If I double the weight and not the movement or the time it becomes necessary to double the force.

If I halve the weight and not the movement or the time, the force is halved.

Forster II 78 v.

[*Drawing*]

If you wish to know the weight of the cord that supports the last pulley, multiply always cubically the weight attached to the foot by the number of the pulleys, and the result of this multiplication will be the

number of the pounds which this last cord receives from the aforesaid weight attached to its foot.

Let us suppose therefore that this weight attached to the foot is four, then you will say: four pounds multiplied by four the number of the pulleys makes sixteen; and then four times sixteen makes sixty-four; and it is multiplied cubically, and this cord above supports sixty-four pounds by the four attached to the feet; and if there were six such pulleys you would say: four times six are twenty-four, and four times twenty-four are ninety-eight (*sic!*); and this great weight is supported by the last cord with the four pounds attached to the foot.

Here it is shown how the four pounds proceeds to double continually; with the addition of each wheel the previous weight is doubled.

Forster II 82 v.

[*Drawing*]

The cord doubles its natural strength as many times as it is suspended in different parts of its length.

Forster II 83 r.

Gravity with suspended cord at every degree of movement makes degrees of weight.

The force that moves gravity on suspended cord will be as great as that which moves this gravity over rollers or balls which are placed upon a surface that is quite smooth — because each is supported exactly.

But at this point a doubt seems to arise, that is by the fifteenth of the first, where it says that the centre of the gravity of a suspended cord is beneath the centre of this cord, and this centre of the gravity desires as far as possible to approach to the centre of the earth; and if you draw this weight cross-wise, fixed weight makes a revolving movement and raises itself up and goes away from the centre of the earth, and so increases weight in its mover. The weight which is resting on balls on a smooth surface always has its centre at an equal distance from the centre of the world, and consequently it does not increase the resistance in its mover.

The resistance created by friction for the movement of weights is separate and remote from this weight.

Reason

This is shown by the things said before, that is that it is clearly seen that the movement made by the weights along the horizontal line does not of itself offer any other resistance to its mover than its natural friction

which it makes with a smooth surface where it touches it; which movement becomes more difficult in proportion as the smooth surface becomes more scoured and rough. And in order to see the truth of this move the said weight upon balls on an absolutely smooth surface: you will then see that it will move without effort.

The weight the movement of which is rendered difficult by the friction which it makes with the smooth surface where it moves, will increase in gravity as it lacks effort in the friction which it has with the smooth surface where it moves.

This is shown as it raises itself on a line that has a considerable slant, for as it were its simple weight is in the force of the mover, and the friction is small.

Forster II 86 r. and 85 v.

[*Drawing*]

Whoever knows how great a weight raises the hundred pounds upwards by this slope knows the capacity of the screw.

If you desire true knowledge of the quantity of the weight required to move the hundred pounds over the sloping road, it is necessary to know the nature of the contact which this weight has with the smooth surface where it produces friction by its movement, because different bodies have different kinds of friction; because if there shall be two bodies with different surfaces, that is that one is soft and polished and well greased or soaped, and it is moved upon a smooth surface of a similar kind, it will move much more easily than that which has been made rough by the use of lime or a rasping-file. Therefore always when you wish to know the quantity of the force that is required in order to drag the same weight over beds of different slope, you have to make the experiment and ascertain what amount of force is required to move the weight along a level road, that is to ascertain the nature of its friction. And if you neither know this nor wish to make trial of it, set up an obstacle in your way, and that goes changing according to the slope of the road whence this weight ought to be drawn. Seeing that different slopes make different degrees of resistance at their contact; and the reason is that if the weight which ought to move is placed upon level ground and for this reason has to be dragged, undoubtedly this weight will be in the first strength of resistance, because everything rests upon the earth and nothing upon the cord which ought to move it. But if you wish to draw it along a very steep road all the weight which it gives

of itself to the cord which sustains it is subtracted from the contact of its friction; but as it is necessary to show another more palpable reason: — you know that if one were to draw it upright grazing and touching a wall somewhat, that this weight is almost all upon the cord which draws it and only a minute part rests upon the wall where it rubs.

Forster II 87 r. and 86 v.

If the centre of the weight be outside the perpendicular of the centre of the screw which moves it:

This weight will show itself heavier to its mover, and the teeth of the screw together with those of the screw-box which encloses them will be oppositely weighed down by two contrary forces.

Forster II 97 r.

Weights work in balances along the line of their perpendicular.

You have in the ninth of my theory that when the weight is attached to the transverse cord within equal angles each extremity of this cord is equally burdened by this weight; moreover the fact of these extremities being at varying distances from this weight does not make any difference.

Forster II 99 r.

Why the small gimlet makes its hole without anything to guide it and the large one requires two or three turns for this hole to be made larger.

Forster II 100 v.

Let the weight be affixed with as many cords as you wish to the arms of the balances, so that you have only to seek, if it is not the perpendicular of the centre of the weight, in what part it intersects with the arm of the balance which is above it.

Forster II 105 r.

[*Diagrams*]

I have affixed three different weights somehow to one of the arms of the balance at three different places chosen by chance, and I would wish on the opposite arm to give a counterpoise to the said weights; which counterpoises are two, that is the one of four pounds and the other of two, and finally I should wish to attach them separately at such a place that they would be equal in weight to three other weights opposite.

Forster II 105 v.

[*Diagrams*]

To one of the arms of the balance I have attached three different weights, that is one of one pound, another of two and a third of three

pounds, and these said weights are at varying distances from each other as chance may have it; now I have a weight of eight pounds and I would wish to set it upon the opposite balance as counterpoise to these three such weights; I ask in what position it is to be placed to make itself equal to those opposite to it: you will do as you see here below.

Forster II 106 r.

The centre of any heavy body whatsoever will stand in a perpendicular line beneath the centre of the cord on which it is suspended.

I ask if you were to suspend a pole outside the centre of its length what degree of slant it will assume.

The pole which is suspended outside the centre of its length by a single cord will assume such a slant as will make with its opposite sides together with the perpendicular of the centre of the cord that supports it, two equal acute angles or two equal obtuse angles.

Forster II 115 r.

[*Sketch*]

If the wheels are of equal height the waggon will move with a sure degree of force. But if you change the two back wheels for wheels of greater height it will move with greater ease. If however in the case of the first wheels you were to change the wheels in front for some less in height, in such a way that in the same manner the wheels in front were low and those behind high, the first movement will have been made more difficult and harder.

Forster II 124 r.

The balance with three equal arms will remain stable of itself in whatever position you may turn it, and the weights will always stand in double proportion, except when one of the arms is in a perpendicular line, because then the proportion will be that of the equality. Take away the perpendicular of the centres of the weights of each arm of this triangular balance, and observe how they stand there with the centre of the balance; and if you find two on one side, take their centre against the centre of the opposite arm and you will see a double proportion of spaces and weights.

Forster II 126 r.

If centres of weights are equidistant from their common centre these weights will be equal in equilibrium.

If perpendiculars of centres of weights are equidistant from the

perpendicular of their common centre these weights will stand equal in equilibrium if they are equal.

For this reason the centre of the world is always movable through the change in the overflowing of the ocean.

Forster II 126 v.

Gravity is all in all the length of its support and all in every part of it.

Why has it been found by experiment that when the pole stands in a slanting line and remains with its parts equidistant to the central line it does not remain slanting but rather becomes horizontal, forming four right angles with the above-mentioned central line?

The answer is that it proceeds from the imperfection of the pole.

Forster II 128 r.

A weight of one pound falls one braccio and gives a blow of a certain force; the question is asked if a weight of half a pound were to fall double the height, or twice from the first height, or twice the weight from half the height or four times from a quarter of the height, if it would produce the same result.

Forster II 130 r.

Every heavy body weighs in the line of its movement.

Forster II 130 v.

[*Diagram*]

Although the time in which the movement of heavy bodies occurs together with the length of this movement is divisible, it does not follow that the act of percussion because made on the surface of these bodies can itself be divided.

Though the figure *s* strikes on the slant *a n* and that it will appear that being fleeting it may not be powerful, it will not fail to be the case that the act of percussion will be much more powerful than if it was a round body and that its rebound will be along the line.

Forster II 131 r.

OF FRICTION

The action of friction is divided into parts of which one is simple and all the others are compound. Simple is when the object is dragged along a plain smooth surface without anything intervening; this alone is the form that creates fire when it is powerful, that is it produces fire, as is seen with water-wheels when the water between the sharpened iron and this wheel is taken away.

The others are compound and are divided into two parts; and the first is when any greasiness of any thin substance is interposed between the bodies which rub together; and the second is when other friction is interposed between this as would be the friction of the poles of the wheels. The first of these is also divided into two parts, namely the greasiness which is interposed in the aforesaid second form of friction and the balls and things like these.

Forster II 131 v.

All things and everything whatsoever however thin it be which is interposed in the middle between objects that rub together lighten the difficulty of this friction.

Observe the friction of great weights, which make rubbing movements, how I have shown in the fourth of the seventh that the greater the wheel that is interposed the easier this movement becomes; and so also conversely the less easy in proportion as the intervening thing is thinner as would be any thin greasy substance; and so increasing tiny grains such as millet make it better and easier, and even more the balls of wood or rollers, that is wheels shaped like cylinders, and as these rollers become greater so the movements become easier.

Forster II 132 r.

That thing which is entirely consumed by the long movement of its friction will have part of it consumed at the beginning of this movement.

This shows us that it is impossible to give or make anything of any absolute exactness, for if you desire to make a perfect circle of the movement of one of the points of the compasses, and you admit or confirm what is set forth above, namely that in the course of long movement this point tends to become worn away, it is necessary to concede that if the whole be consumed in the whole of a certain space of time, the part will be consumed in the part of this time, and that the indivisible in the indivisible time may give a beginning to such consumption.

And thus the opposite point of these compasses which turns in itself over the centre of this circle, at every stage of movement is in process of being itself consumed and of consuming the place on which it rests; whence we may say that the end of the circle is not joined with its beginning, rather the end of such line is some imperceptible part nearer towards the centre of such circle.

The friction made by the same weight will be of equal resistance at

the beginning of its movement although the contact may be of different breadths or lengths.

The greatness of the contact made by compact bodies in their friction will have so much more permanence as it is of greater bulk; and so also conversely it will be so much less enduring as it is of less size.

That which is said is shown in the case of the friction made by the head of the handle of the knife, for in equal time it is more perceptible than that which is made by its point. Forster II 133 r. and 132 v.

Impetus transports the movable thing beyond its natural position.

Every movement has terminated length, according to the power which moves it, and upon this one forms the rule.

Every movable thing which acquires velocity in the act of movement is moved under its natural movement, and so conversely when it loses it moves with accidental movement. Forster II 141 v.

[*Sketch*]

Proof how these cords have equal weight.

If the centre of the weight is located in the middle of the equal number of cords which support it this weight is equally distributed between each cord.

Here one is supposing the pole to be unbendable, and not taking count in cases like these of the weight of the instrument but only of the weight attached. Forster II 142 r.

The gravity which is moved in conformity with its natural position with every degree of movement acquires a degree of speed.

And if the gravity shall move in opposition to its natural position with every degree of movement it loses a degree of speed.

In transverse movements the degrees of diminution are in the case of that which goes upward. Forster II 144 r.

The pole which is suspended at its extremities by two cords divides its weight equally between these cords.

But if one of the cords remains fixed and the other moves towards it, weight moves from this fixed cord and joins itself to the weight of the movable one.

The more a cord is moved towards the centre of the pole the more weight is taken from the other cord.

The weight which is moved within the cords is in the same proportion to the first weights as is the movement made by the cord to the remainder of the pole. Forster II 150 r.

But if the one cord is fixed and the other moves towards it, weight moves from this fixed cord and is united with that of the movable one. Forster II 150 v.

The pole which at its extremities is suspended to two cords divides its weight equally between these cords.

But if one of the cords is moved towards the other every degree of movement corresponds to this change of weight.

The weight that moves between the cords has such proportion to the first weights as the movement made by the cord has to the remainder of the pole.

The remainders of the weights which will be left to these cords will have together such proportion as the opposite spaces which are enclosed between the two cords and the centre of the pole have between them. Forster II 151 r.

The variety of the weight which this cord acquires by its movement will have such proportion with that of the first weight as its movement has with the remainder of the pole.

And the weights that are changed on the said cords will have together such proportion as the spaces which intervene between the two cords and the centre of the pole have between themselves.

And weights which have remained on the said cords will have together such proportion as oppositely have the spaces that are enclosed between the centre of the pole and the two cords.

The weight which moves between the cords has such proportion to the first weights as the movement made by the cord has to the remainder of the pole. Forster II 151 v.

The pole which is suspended by two cords at its extremities divides its weight equally between these cords; and although these cords may be moved equally towards the centre of the pole they do not vary their first weight.

But should one of the cords towards the centre of the pole be moved and the other remain fixed at its extremity every degree of movement occasions among them variation of weight; and the remainder of the

weights of the cords will have such proportion one with another as have the spaces opposite to them which are enclosed between the centre of the pole and the two cords.

Forster II 152 r.

Such proportion as there is between those spaces which are enclosed between the centre of the length of the suspended pole and the two cords which sustain this pole, such will there be one with another the opposite weights which this pole gives of itself and the cords which support it.

The thing which moves by natural movement at every degree of movement acquires degrees of speed, which degrees will bear the same proportion, the last to the last but one, as the second has to the first.

Forster II 152 v.

The pole which is suspended by the extremities of its length to two cords divides its weight equally between these cords.

But if the one of the cords towards the middle of the length of the pole be moved there will be the same proportion between the weight separated from the stationary cord and joined to that which moved, as between the movement made by the cord and the remainder of the pole which is supported between the two cords.

But if the one of the cords is stationary and the other is moved towards it, weight departs from this stationary cord and unites itself to that which is moved, which has the same proportion to the remaining part of the first weight as the movement made by the cord has to the first space of these cords.

Forster II 153 r.

Whoever speaks of arms of a balance means them to be of equal thickness and weight if they are of equal length.

The spaces which are interposed between the centre of the arms and the pole of the balance have between them such proportion as the opposite weights have with them as the one arm serves as counterpoise to the other.

The spaces which are enclosed between the centre of the two arms of the balance and the pole of this balance have between them such proportion as is that which the weights of these arms have between them together with their length.

Forster II 154 v.

The centre of the length of each arm of the balance is the true centre of its gravity.

The arms of the balance make of themselves a counterpoise the one

to the other; which counterpoise will have with these arms as many varieties as the proportions of these arms will be varied.

That proportion which the one arm of the balance has to its opposite arm such the weight will have with it as this lightens the opposite arm. Forster II 155 v.

The centre of the length of each arm of the balance is the true centre of its gravity.

Arm of balance is said to be that space which is found between the weight attached to this balance and its pole.

That proportion which exists between the spaces that come between the centres of the arms and the pole of the balance, is as that of the opposite weights which the one arm gives of itself in counterpoise to the other with its own arm which is the counterpoise.

Arms of the balance are said to be those which are found between the centres of the weights affixed to it and the pole of the said balance.

Forster II 157 r.

Where the support makes less resistance there the weight supported by it shows itself heavier; and that part of the support makes less resistance which is more remote from its foundation. Forster II 157 v.

Of the pyramids of equal height the proportion of the weight will be as that of the bases.

Pyramids of varying lengths upon equal bases will be of as many different proportionate weights as their lengths are varying; the pyramids of equal bases with different lengths enclosed in a parallelogram will be of equal weight. Forster II 158 r.

[*Sketch*]

If a chimney-sweeper weighs two hundred pounds how much force does he exert with his feet and back in the chimney? Forster III 19 v.

[*Sketch*]

I ask why the blow of the hammer causes the nail to jump out.

Forster III 20 v.

The air which closes itself up with fury behind the bodies which move through it offers more resistance than that which remains stationary, consequently the ball when struck covers a greater distance than the jump or the leap can serve as the occasion of. Forster III 27 r.

Why it is first the blow rather than the movement caused by it; the

blow has performed its function before the object has started on its course. Forster III 28 r.

[*Sketch*]

It will be impossible to break that support which is the centre of the gravity placed upon it; and the centre of this itself will be the perpendicular upon the centre of its base. Forster III 29 r.

A blow is an end of movement created in an indivisible period of time, because it is caused at the point which is the end of the line of the movement made by the weight which is the cause of the blow. Forster III 32 r.

No animal can simply move more weight than is the load that finds itself outside the centre of its support. Forster III 34 r.

The movement made by the arrow in ordinary simple flight will increase as much as the power of the composite movement of a second tethered (?) [*apicata*] flight. Forster III 38 v.

There will be such proportion between the amount of movement of a stone that is moved and that of the thing that is moving, one time more than another, as the time of the moving thing is swifter on the one occasion than on the other. Forster III 39 r.

The infinite movements of the varieties of the instruments which may be constructed for drawing weights will be of equal power in the completed movement of the thing moving and of that moved. Forster III 40 v.

Define to me why one who slides on the ice does not fall. Forster III 46 r.

Prove which keeps its movement more, a wheel that revolves on the flat or on an edge.

Prove whether the impetus of the revolving of the wheels acquires force from its mover. Forster III 48 r.

Every free heavy body when falling directs its course to the centre, and that part which weighs most will be nearest to the centre of the world. Forster III 51 r.

As is the proportion one to another of the spaces that are enclosed between the perpendicular of the weight attached to the slanting beam

and the perpendiculars of the extremities of this beam, so will be that of the weights of the opposite extremities of the beam. Forster III 51 v.

If two opaque bodies are moved one against the other with intersecting movement the two bodies will seem three; and in like manner one thing will seem two, and the two without intersecting movement will appear to be four as the wings of birds when flying. Intersected movement. Simple movement. Forster III 55 r.

The centre of gravity of any heavy suspended body will always fall below the centre of its support.

The counterpoise divides with its weight if the beam divides it in half. Forster III 60 r.

If the sea bears down with its weight upon its bed, a man who lay on this bed and had a thousand braccia of water on his back would have enough to crush him. Forster III 66 r.

The desire of every heavy body is that its centre may be the centre of the earth. Forster III 66 v.

Friction produces double the amount of effort if the weight be doubled. Forster III 72 r.

[*Sketch*]

I ask how great a weight ought to be placed at *m* in order to draw one hundred pounds at *n*; and by degrees to ascertain what weight it will be which will overcome the other, giving the cord that goes from the one weight to the other sometimes one twist round the beam, sometimes two or three or four; and similarly if the beam be triangular or square or of a greater number of angles. Forster III 73 v.

I ask which is swifter — a spark going upwards and living or turning downwards in death. Forster III 75 v.

Everything attached or united to bodies that have been struck will move against the place of the blow.

That part of the cord that is twisted over the beam that lies equally, will press the part of the beam more which is nearer to the greater of the two weights that are fastened to the extremities of the cord.

Forster III 77 v.

[*Duration of movement of liquid*]

The movement of the liquid made in any direction, proceeds as far in the revolution it has commenced as there lives in it the impetus given to it by its first mover. Fogli B 28 r.

In the same space the arrow carries farther straight upwards than it does obliquely, and this arises from the fact that when the direction is upwards the arrow or bullet falls by the line in which it rose and obliquely it forms an arch. Quaderni II 15 r.

[*Law of inertia*]

The thing which moves will be so much the more difficult to stop as it is of greater weight. Quaderni IV 10 v.

The thing which moves itself acquires as much space as it loses. Quaderni IV 15 v.

[*Of long and short steps*]

When one is descending one takes short steps because the weight rests on the hinder foot but when one is ascending one takes long steps because the weight is thrown on to the foot in front. Quaderni VI 18 r.

That wheel will revolve more easily which has its axis of less thickness. Quaderni VI 21 r.

It is proved how the air does not push the movable thing since it is separated by the power of its mover.

If to the movable thing which separates itself from its mover there was given the perception of the movement of the air which pushed it behind it would happen that the bullet of the carbine in penetrating a leathern bottle full of water would immediately lose its movement at the beginning of its penetration, because instantly the water would close the entrance and separate it from the air which drives it; as to which experience shows to the contrary, seeing that this ball after the said penetration of the water moves for a long time. And if you were to say that the fury of the movement of the air or of the water, through which this bullet passes, which turns to fill up the vacuum from which the bullet departs point by point, is that which forms a wedge between the back of the bullet and the rest of the air which stays behind it; here the reply is that the air is more powerful and more compressed in front of the bullet than that on the opposite side, because this opposite side is the air reflected by the percussion of the bullet. 'The

reflection of anything is always of less power than its incidence'; and if you should gainsay me as to this by urging that this power cannot be infused in the body that is moved, because 'no movable thing moves of itself, unless its members exert force in other bodies outside it', as when a man in the centre of a boat pulls the rope attached to the stern of it, in order to give movement to the ship, which work is useless unless this rope is fastened to the bank where he wishes to move, or unless he pushes the oars in the water or the pole on the bottom; therefore the power not being in the air which drives the said bullet it is necessary that it is poured into the bullet; and if it is thus poured what has been said above serves as an example of the result; and in addition to this, this power so poured in would be of equal force through all its sides, because it would be spread equally in equal quantities through all that bullet; this however is not so, and the other premise you do not grant me; let us therefore seek for a third to which no exception can be taken. 'The potency of the mover is separated from it entirely and applied to the body moved by it, and it goes on to consume itself in course of time in penetrating the air which is always compressed before the movable thing'. And this happens because 'every impression is preserved for a long time in the object on which it is impressed', as is seen in the circles created by its percussion within the surface of the water, which move within the water for a long distance, and in the eddies and waves, formed in one spot, and carried by the impetus of the water to another, without their destruction; and radiance creates the same effect in the eye, and sound in the ear. But if you would also say that the air preserves the power of the mover which accompanies it and pushes its movable thing, how are we to reconcile to this the case of the wheel which in a storm of wind turns for a long time, although its mover is separated from it?

It is not air that moves it for as it is equally distributed round its axis as regards its outline and its weight, the wind which embraces it on one side only, if it caresses the half of the wheel which flies from it, opposes and resists the other half of the wheel which moves against it, and consequently the wind which stops the movement as much as it aids it does not render this wheel any service or disservice; therefore the potency of the mover was left imprinted on the outside of the wheel and was not poured into it or into the air that lay about it. If you wish to see the movement the air makes when it is penetrated by a movable thing take an example in the water, that is, underneath its surface, for it may

have mingling with it thin millet or other minute seed which floats at every stage of height of the water; and afterwards place some movable thing within it which floats in the water and you will see the revolution of the water, which ought to be in a square glass vessel shaped like a box. 'Every natural act is communicated from the doer to the object in the shortest possible time'; and the air beaten and compressed by the movable thing that moves within it need not therefore be that which restores the vacuum, for the movable thing makes a succession of vacuums as it flies from it; but it is that which is nearer the opposite side of the movable thing, that is that by which it leaves the path, that continually rarefies the condensation already made; and by means of this rarefaction the before mentioned vacuum is restored. 'Never, in the same time will the greater power be subdued by the lesser power': therefore, the swift movement of the rarefied air in order to fill up the place in the vacuum, caused by the movable thing departing from it, is much weaker than that which is continually being compressed before the movable thing; of which compression the air that is thinner than it will never be the cause. Therefore we have concluded that the movable thing does not move on account of the wave of the air created by the impetus of the mover. And if you wish to say that the flooding of the air which escapes before the movable thing is that which prepares the movement of the movable thing, together with the air, and runs after it in order to restore the rarefaction of the air, to this one replies that this air is here flooded by the movable thing and not by itself, and 'it is impossible that at one and the same time the mover should move the movable thing and the movable thing move its mover': therefore, your reason does not hold, because if the aforesaid flooding were that which had to draw itself after the cause of its movement, 'it is impossible that any thing of itself alone can be the cause of its creation; and those things which are of themselves are eternal'. Leic. 29 v.

Gravity comes into being when an element is placed above another element thinner than itself.

Gravity is caused by one element having been drawn within another.
Sul Volo (F.M.) 1 r.

Gravity is caused by one element being situated in another; and it moves by the shortest line towards its centre, not by its own choice, not because the centre draws it to itself; but because the mean in which it finds itself cannot withstand it. Sul Volo (F.M.) 2 v.

XX

Mathematics

'There is no certainty where one can neither apply any of the mathematical sciences nor any of those which are based upon the mathematical sciences.'

As I have shown, here at the side [*diagram*], various ways of squaring the circles, that is by forming squares of a capacity equal to the capacity of the circle, and have given the rules for proceeding to infinity, I now begin the book called 'De Ludo Geometrico', and I give also the method of the process to infinity.

C.A. 45 V. a

A body is something of which the boundaries form the surface.

The surface is not part of the body nor part of the air or water that surround it, but it is a common boundary. . . . in which the body ends in contact with the air, and the air in contact with the . . .

C.A. 91 V. a

What is that thing which does not give itself, and which if it were to give itself would not exist?

It is the infinite, which if it could give itself would be bounded and finite, because that which can give itself has a boundary with the thing which surrounds it in its extremities, and that which cannot give itself is that which has no boundaries.

C.A. 131 r. b

Surface is the touching-part [contingenzia] of the extremities of bodies, that is it is made by the extremities of the body of the air, together with the extremities of the bodies which are clothed by this air, and it is that which completes and forms with this air the boundary of the bodies surrounded by the air, and completes this air with the bodies clothed by it, and it does not participate either in the body which surrounds it or in that which is surrounded by it. It is rather the true common boundary of each of these, and it is that which divides the one body from the other, as one may say the air or the water from the body that is enclosed in these.

C.A. 182 r. a

Arithmetic is a mental science and forms its calculations with true and perfect denomination; but it has not the power in its continuing quantities which irrational or surd roots [radici sorde] have, for these divide the quantities without numerical denomination.

C.A. 183 V. a

Surface is a flat figure which has length and breadth and is uniformly without depth.

C.A. 246 v. b

A point is not a part of a line.

Tr. 63 a

[*With drawing*]

[*To ascertain the width of a river*]

If you would ascertain the exact distance of the breadth of a river proceed as follows: — plant a staff upon the river bank at your side and let it project as far from the ground as your eye is from the ground; then withdraw yourself as far as the span of your arms and look at the other bank of the river, holding a thread from the top of the staff to your eye, or if you prefer it a rod, and observe where the line of sight to the opposite bank meets the staff.

B 56 r.

[*With drawing*] [*A level resting on a support from the base of which there is a cord to its ends*]

This is the way that the level should be made: that is it is two braccia long, an inch thick, and square; and it should be of pine so that it may not twist, and have in the top of it a groove of the thickness of a finger and of the same depth. Then moisten the cord and fill the groove with water, and lower first the one end and then the other until the water stands level with the sides. Then proceed to wipe away with the finger the water that flows over the ends of the groove until these become dry, and fix two pieces of iron at *m n*, of the thickness of the cord, and see that one fastens the other and the thing seen.

B 65 v.

A thing which moves acquires as much space as it loses.

E 7 v. and 25 v.

OF MECHANICS

Mechanics is the paradise of the mathematical sciences because by means of it one comes to the fruits of mathematics.

E 8 v.

OF THE SQUARING OF THE SURFACE OF A SPHERE WITH STRAIGHT MOVEMENT

The knowledge of the aliquot part gives knowledge of its whole; whence it follows that the squaring of the eighth part of the surface of a sphere gives knowledge of what is the square of the whole of this sphere; and let this be the knowledge of the eighth of the sphere: *a b c*.

Second figure. In the second figure *c d e* one divides the eighth part of the spherical surface in parallels of equal breadth and straightens the curve of the two sides *c d* and *d e*; this is done with movement upon a level place.

Third figure. In this third figure there is that which was promised in the second, and the straightened sides *f g* and *g h* are all the parallels of the second, which are enlarged and elongated by means of their movement, because there are the same number of parallels made upon the extended lines *f g* and *g h* (which are equal to each other); the whole being increased the parts also have increased.

Fourth figure. In the fourth figure one makes equal pyramidal divisions as shown in *f g h*.

Fifth figure. In the fifth figure the points of the pyramids are opened and enlarged, the same number of pyramids are reproduced, and the square *n m o p* is formed; but first by movement one straightens the line *i l*, and one has the fourth part of the spherical surface.

The junction of the curves *c d e* straightened at *f g h* forms a rectangle.

E 24 r.

DEFINITION OF HELIX

A helix is a single curved line the curve of which is uniformly irregular and it goes revolving round a point at a distance uniformly irregular.

DEFINITION OF HEMISPHERE

A hemisphere is a body produced by a half sphere contained by the circle and the surface of the half sphere.

The movement of the hemisphere commenced by the circumference of its greatest circle ends in the middle of this hemisphere, after having described a spiral curve.

This is proved by the second concerning compound impetus which says: 'Of compound impetus one part will be as much slower than the other as it is shorter', and: 'That will be shorter which is farther distant from the direct line of the movement made by its mover'. Therefore the movement of the hemisphere being made up of the movement of many whole revolutions is of the same movement as a half revolution.

E 34 v.

MENSURATION

When you wish to measure the breadth of a river withdraw from its bank to a somewhat greater distance than the width of the stream and observe some fixed mark on the opposite bank of the river. Let *a b* represent the width of the river, and *a c* the space to which you withdraw from the river, this being somewhat longer than the width of the river.

Next draw at the end of this distance a perpendicular line of whatever length you please, and let this be the line *c d*.

And from this [spot] *d* observe again the mark *b*, which you noted on the opposite side of the river, and make a mark f^1 upon the [opposite] bank at the point which is in the same line *d b*. After having done this bisect the perpendicular line *c d* at the point *e* and from this point *e* make another perpendicular line at exact right angles, and make a mark where it intersects the line $d\ f^1$, and from this make the third perpendicular line $g\ f^2$. You will thus have formed the quadrilateral $c\ f^2\ e\ g$, of which you know that the side $c\ f^2$ is equal to $f^2\ b$, because as the point *e* is in the centre of the line *c d* so the point f^2 is in the centre of the other line *c b*; then take $a\ f^2$ (from the bank) from $f^2\ c$, that is $f^2\ h$, and you have remaining *h c*, a distance equal to the width of the said river.

E 51 v.

All the pyramids made upon equal bases in parallel spaces are equal to each other.

The greatest pyramid that can be drawn from a cube will be the third of the whole cube.

E 56 r.

The intercentric line is said to be that which starts from the centre of the world and which rising therefrom in one continuous straight line passes through the centre of the heavy substance suspended in an infinite quantity of space.

E 69 r.

OF THE FIVE REGULAR BODIES

Against some commentators who blame the ancient inventors from whom proceed the grammars and the sciences and campaign against the dead inventors, and why they have not discovered through idleness how to become inventors themselves, and how with so many books they set themselves continually to confute their masters by false arguments:

They say the earth is hexahedral,[1] that is to say cubical, that is to say

[1] MS. has *tetracedronica coe cubica* — presumably a slip of the pen.

a body with six bases, and they prove this by saying that there is not among regular bodies a body of less movement or more stable than the cube. And they attribute to fire the tetrahedron, that is the pyramidal body, this being more mobile according to these philosophers than the earth; for this reason they attribute the pyramid to fire and the cube to the earth.

Now if one had to consider the stability of the pyramidal body and to compare it with that of the cube, this cube is without any comparison more capable of movement than the pyramid, and this is proved as follows:

The cube has six sides, the regular pyramid four, and these are placed here in the margin at *a b*; *a* is the cube, *b* the pyramid. In order to define this proof I will take a side of the cube and a side of the pyramid which will be *c d*; I maintain that the cube *c* will be more adapted to a movement of circumvolution than the pyramid *d*. And let *e f*, below, represent the commencement of these movements. I say that as a matter of fact if the base of the cube and the base of the pyramid rest upon the same plane the pyramid will turn the third of its bulk to fall upon its other side, and the cube will turn the fourth part of its circuit to change the other side in order to make a base. From these two demonstrations the conclusion follows that the cube will turn completely with the change of its four sides upon the same plane, while the triangle or pyramid will turn completely with three of its sides upon the same plane. The pentagon turns all its five sides and so the more sides there are the easier is the movement because the figure approaches more nearly to a sphere. I wish it to be inferred therefore that the triangle is of slower movement than the cube and that therefore one should take the pyramid and not the cube for the earth.

F 27 V.

OF PROPORTION

If from two like wholes there be taken away like parts there is the same proportion between part and part as there is between whole and whole.

It follows that if of these two circles the one is double the other, the quarter portion of the larger is double the quarter portion of the smaller.

And there is the same proportion between one remainder and the other as between one whole and the other.

And the same proportion between part and part as there is between remainder and remainder.

When two circles touch the same square at four points one is double the other.

And also when two squares touch the same circle at four points one is double the other.

G 17 r.

GEOMETRY

The circle that touches the three angles of an equilateral triangle is triple the triangle that touches the three sides of the same triangle.

The diameter of the largest circle made in the triangle is equal to two thirds the axis of the same triangle.

G 17 v.

The proportion of circle to circle is as that of square to square made by the multiplication of their diameter by itself. Now make two squares in such proportion as pleases you, and then make two circles, of which one has for its diameter the side of the greater square, and the other has for its diameter the side of the lesser square.

Thus by the converse of the first proposition you will have two circles which will bear the same proportion one to another as that of the two squares.

G 37 r.

TO OBTAIN THE CUBE OF THE SPHERE

When you have squared the surface of the circle divide the square into as many small squares as you please, provided that they are equal one to another, and make each square the base of a pyramid, of which the axis is the half diameter of the sphere of which you wish to obtain the cube; and let them all be equal.

G 39 v.

[*Circles and squares*]

Circles made upon the same centre will be double the one of the other, if the square that is interposed between them is in contact with each of them. And double the one of the other will be the squares formed upon the same centre, when the circle that is set in between them touches both the squares.

This is proved because of the eight triangles of which the larger square is composed the lesser square contains four.

There is the same proportion between circle and circle that there is between square and square, formed by the multiplication of their diameters.

Of all the parts of circles which may be in contact inside a right angle the greater is always the equal of all the less; and of all the parallels which receive these parts in themselves the greater always contains and is the equivalent of all the small parallels formed in this right angle *a b c*.

G 40 r.

DEFINITION OF FOUR GROUPS OF PARALLELS

Parallel figures are of four kinds. The first is enclosed between two straight and equidistant lines; the second is between two equidistant lines of uniform curve; the third is between two equidistant lines of varying curve, such as the parallel lines made around the centre of the circle; the fourth is formed of a single line curved round a point at an equal distance, that is the line of the circumference round the centre of its circle.

And all these lines are of uniform nature since with movement the straight line becomes curved and the curved line becomes straight, by means of the impressions of the straight planes upon the curved and of the curved upon the straight.

By one of the 'Elements' [of Euclid].

All the rectilinear triangles made upon equal bases and between parallel straight lines are equal to one another.

G 59 r.

If from unequal things there be taken away equal parts the remainders will be unequal; not in the former proportion but with a greater excess of the greater quantity.

G 69 v.

ARITHMETIC

Every odd number multiplied by an odd number remains odd.

Every odd number multiplied by an even number becomes even.

G 56 v.

[*Of squaring the circle*]

Animals that draw chariots afford us a very simple demonstration of the squaring of a circle, which is made by the wheels of these chariots by means of the track of the circumference, which forms a straight line.

G 58 r.

OF SQUARING THE CIRCLE AND WHO IT WAS WHO FIRST HAPPENED TO DISCOVER IT

Vitruvius while measuring the mile by means of many complete revolutions of the wheels that move chariots, extended in his stadia

many of the lines of the circumference of these wheels. He learnt these from the animals that are movers of these chariots, but he did not recognise that that was the means of finding the square equal to a circle. This was first discovered by Archimedes the Syracusan who found that the multiplication of half the diameter of a circle by half of its circumference made a rectilinear quadrilateral equal to the circle.

G 96 r.

There is no certainty where one can neither apply any of the mathematical sciences nor any of those which are based upon the mathematical sciences.

G 96 v.

That force will be more feeble which is more distant from its source.

H 71 [23] v.

Every continuous and united weight which thrusts transversely rests upon a perpendicular support.

If the weight is discontinuous and limited as when it is liquid or granulated, it will make its thrust upon all sides, and making it thus the pressure that is exerted upon the sides serves to lighten that upon the foundations.

H 74 [26] r.

Should the contact which the thing united makes with the earth on which it is supported be not in the line of its motive power, it will prove heavier in proportion as it is farther distant from the line of its motive power.

H 113 [30 r.] v.

The heaviest part of every body that is moved will be the guide of its movement.

H 115 [28 r.] v.

Similarity does not imply equality.

I 16 r.

The fact that a thing may be either raised or pulled causes great difference of difficulty to its mover; for if it is a thousand pounds and one moves it by simply lifting it it shows itself as a thousand pounds, whereas if it is pulled it becomes less by a third; and if it is pulled with wheels it is diminished by as many degrees in proportion to the size of the wheel, and also according to the number of the various wheels. And with the same time and power it can make the same journey, with different degrees of time and power also in the same time and move-

ment; and it does this merely by increasing the number of the wheels, on which rest the axles which would also be increased.

I 17 r.

By the ninth of the second of the Elements, which says that the centre of every suspended gravity stops below the centre of its support, therefore:—

The central line is the name given to what one imagines to be the straight line from the thing to the centre of the world.

The centre of all suspended gravity desires to unite with the central line of its support.

And that suspended gravity which happens to be farther removed from the central line of its support will acquire more force in excess of that of its natural weight.

Now in conclusion I affirm that the water of the spiral eddy[1] gives the centre of its gravity to the central line of its pole, and every small weight that is added on one of its sides is the cause of its movement.

I 22 v.

[*The Wonders of Mechanics*]

Rule [*Diagram*]

Pivots of the greatest force serve for the movements that go and return such as those of bells, saws and things of the same nature.

A pound of force at *b* has for result at *m* ten thousand thousands of millions of pounds, and the figure opposite does the same, being of the same nature and only differing in that the wheels are whole as they have to turn always in a single direction. And know that when the first above gives a hundred thousand thousands of millions of turns, that below only gives one complete turn.

These are the wonders of the science of mechanics.

In this manner one may make a bell to swing on a pivot so that it will be sounded by a slight wind, the bell having its opposite weights equal and equidistant from its centre.

I 57 [9] v.

[*Diagram*]

This arrangement will produce a revolving movement of such duration that it will appear incredible and contrary to nature, because it will make much movement after that of its mover. And it causes the weight *m* to fall from such a height that the wheel gives thirty revolutions and more, and then remains free after the manner of a spinning top; and in order to avoid noise this stone ought to fall upon straw.

[1] MS. *dele uiti.*

And to make one wheel greater than another down in succession the one below the other, is only necessary in order that the rim of the wheel below may not stop and impede the pivot of the other.

I 58 [10] r.

PROPORTION IN ALL THINGS

Proportion is not only found in numbers and measurements but also in sounds, weights, times, positions, and in whatsoever power there may be.

K 49 [48 and 15] r.

How one of Xenophon's propositions is incorrect:

If unequal things are taken away from unequal things and these are in the same proportion as the first inequality, the remainders will have the same proportion in their inequality. But if from unequal things equal things are taken away the remainders will still be unequal, but not in the same proportion as before.

Consider these examples: in the first place let the parts taken away be in the same proportion as the wholes, that is let 2 and 4 stand for the two wholes so that the one is double the other. Then take 1 away from 2, there remains 1; take 2 away from 4, there remains 2; and these remainders have the same proportion as the wholes and as the parts taken away. Therefore if 1 be taken from 2 and 2 from 4 there remains the same proportion as at first, that is 1 and 2 which is double as I said before: it would follow that whoever should take away equal things would change the former proportion; that is to say that if from two numbers one of which is double the other such as 2 and 4 you were to take away an equal thing, that is you took 1 from 2 and 1 from 4, there would be left 1 and 3, that is numbers of which one would be three times the other and therefore more than double in difference.

You therefore, Xenophon, who wished to take away equal parts from unequal wholes, believing that although the remainders were unequal they were still in the same proportion as at first, you were deceiving yourself!

K 61 [12] r. and v.

DEFINITIONS OF A STRAIGHT LINE

First. A straight line is that of which each part finds itself of equal height.

Second. A curved line is that which has a uniformly varying height towards its extremities which are of equal height.

The first definition and the second are incorrect because a thing of

equal height must have every part of its bulk equally distant from the centre of the world. So the curve *f b o* would be straight because it is at a uniform distance from this centre, and the straight line *a b c* would be curved, because every part of its length varies uniformly according to the distance of the parts enclosed within extremities that are at equal distance from the centre of the world.

And if you say that the straight line is that which receives three points of equal height in its extent you still say wrong.

But if you say that a straight line is the shortest between two given points you will give its true definition. K 78 [30] v. and 79 [31] r.

[*With drawings*]

The circle is the equal of a rectangular parallelogram made of the fourth part of its diameter and the whole of its circumference, or you may say of the half of its diameter and of its periphery (circumference).

As though one were to suppose the circle *e f* to be resolved into an almost infinite number of pyramids, and these being then extended upon the straight line which touches their bases at *b d* and the half of the height being thus taken away, so making the parallel *a b c d*, this being precisely equal to the given circle *e f*.

With regard to the circumference of the circle it is desirable to measure the quarter with a piece of bark of cane, in its spiral curve and stretching it out, and to make a rule as to where is the centre of the circle from which the movement of the extremity of the measurement is directed, and similarly the centre of the movement of many of its parts, and to make the general rule.

The circle is a parallel figure, because all the straight lines produced from the centre to the circumference are equal and fall upon the line of the circumference between equal angles and spherical lines. And the same thing happens with the transversal lines of the parallelogram, namely that they fall upon their sides between right angles.

All rectilinear pyramids, and those of curved lines formed upon the same bases and varying uniformly as to the breadth of their length between parallel lines of circumference, are equal.

K 79 [31] v. and 80 [32] r.

Of pyramids of equal bases there will be found the same proportion in the slopes of their sides as that of their heights. L 41 r.

Vitruvius says that small models are not confirmed in any operation by the effect of large ones. As to this, I propose to show here below that his conclusion is false, and especially by deducing the self-same arguments from which he formed his opinion, that is by the example of the auger, as to which he shows that when the power of a man has made a hole of a certain diameter a hole of double the diameter cannot then be made by double the power of the said man but by much greater power. As to this one may very well reply by pointing out that the auger of double the size cannot be moved by double the power, inasmuch as the surface of every body similar in shape and of double the bulk is quadruple in quantity the one of the other, as is shown by the two figures *a* and *n*.

[*Drawing*] *a n*.

Here one removes by each of these two augers a similar thickness of wood from each of the holes that they make; but in order that the holes or augers may be of double quantity the one of the other they must be fourfold in extent of surface and in power. L 53 r. and 53 v.

The right angle is said to be the first perfect among the other angles, because it finds itself at the middle of the extremities of an infinite number of other kinds of angles which differ from it, that is of an infinite number of obtuse angles and an infinite number of acute angles, and all these infinite angles being equal between themselves it finds itself equidistant to each of them, being in the middle. M cover v.

THE THIRD LESSON OF THE FIRST

Triangles are of three kinds, of which the first has three acute angles, the second a right angle and two acute angles, and the third an obtuse angle and two acute angles.

The triangle with three acute angles may be of three different shapes of which the first has three equal sides, the second two equal sides and the third three unequal sides.

And the right-angled triangle may be of two kinds, i.e. with two equal sides and with three unequal sides. M I r.

The right-angled triangle with two equal sides is derived from the half of the square. And the right-angled triangle with three unequal sides is formed by the half of the long tetragon [rectangle], and the obtuse-angled triangle with two equal sides is formed by the half of the rhombus cut in its greatest length.

The square is the name applied to a figure of four equal sides which form within them four right angles, that is to say that the lines that compose the angles are equal to each other.

M I v.

LONG TETRAGON

The long tetragon [rectangle] is a surface figure contained by four sides and four right angles; and although its opposite sides are equal it does not follow from this that the sides which contain the right angle may not be unequal between themselves.

The rhombus is of two kinds: the first is formed by the square and the second by the parallelogram; the first has its opposite angles equal and likewise all its sides equal; its only variation consists in that no side ends in equal angles but with an acute angle and an obtuse angle.

M 2 r.

RHOMBOID

The rhomboid is the figure that is formed from the rhombus, but whereas the rhombus is formed from the square the rhomboid is formed from the rectangle. It has the opposite sides and angles equal to each other but none of its angles is contained by equal sides.

Parallel or equidistant lines are those which when extended continuously in a straight line will never meet together in any part.

M 2 v.

Every whole is greater than its part.

If [a thing] is neither larger nor smaller it is equal.

M 3 r.

OF FIVE POSTULATES

That a straight line may be drawn from one point to another.

That with a centre it is possible to make a circle of any size.

That all right angles are equal to each other.

When a straight line intersects two straight lines and the two angles on one side taken together are less than two right angles these two lines extended on this side will undoubtedly meet.

Two straight lines do not enclose a surface.

M 6 r.

THE THIRD LESSON OF THE TENTH

Of the comparison made between the continuous and the definite quantity, and how the continuous may have its parts communicating,

that is to say measured by a common measure as would be a measure of one braccio, a measure that goes four times in a line of four braccia, and then three in a length of three braccia; and so forms a unity which enters four times in four numbers and also enters three times in three numbers; and there is the same proportion between four braccia and four numbers as there is between one number and one braccio. M 6 v.

OF FIVE [SIX?] POSTULATES

The boundaries of the line are points, the boundaries of the surface are lines and the boundaries of the body are surfaces.

That a straight line may be drawn from one point to another.

And this line may also be extended as much as one pleases beyond these points but the boundaries of this line will always be two points.

That upon the same point one may make many circles.

All right angles are equal to each other.

Parallel lines are those upon which if a transversal line be drawn four angles are formed, which when taken within [on one side?] equal two right angles.

M 7 r.

If two squared surfaces have the same proportion to each other as their squares, their sides will be corresponding, that is commensurable in length.

And if there are two squared surfaces of which the sides are commensurable in length it will follow that the proportion between them will be as that of their squares.

And if the squared surfaces are not in the same proportion one to another as are their squares, their sides will be incommensurable in length.

M 9 r.

If two things are equal to a third they will be equal to one another.

M 13 r.

If from equal things one takes equal things away the remainders will be equal.

M 15 r.

A straight line is that in which if one takes a point in any position outside it, at such a distance that its length may share precisely such a given line, and any straight line be drawn from the said point to each of the said partitions, this line can be divided precisely in the same way by each of these partitions.

Let us say that the line of which the proof has to be made is *b f*, that the given point is *a*, that the space from the point to the extremity of the line is *a b*: and that the lengths (partitions) *b*, *c*, *d*, *e*, *f* each of itself is equal to *a b*: I affirm that the line *a c* is double the space *a b*, and the line *a d* is triple, *a e* quadruple and *a f* quintuple.

M 13 V. and 14 r.

NINE PROPOSITIONS

The things which are equal to the same thing are also equal to each other. And if to equal things one adds equal things the wholes will still be equal.

And if from equal things one takes away equal things the remainders will still be equal. And if from unequal things one takes away equal things the remainders will be unequal. And if two things are equal to another thing they will be equal to each other. And if there are two things which are each the half of the same thing each will be equal to the other. And if one thing is placed over another and touches it so that neither is exceeded by the other these things will be equal to each other. And every whole is greater than its part.

M 16 r.

Geometry is infinite because every continuous quantity is divisible to infinity in one direction or the other. But the discontinuous quantity commences in unity and increases to infinity, and as it has been said the continuous quantity increases to infinity and decreases to infinity. And if you allow yourself to say that you give me a line of twenty braccia I will tell you how to make one of twenty-one.

M 18 r.

All the angles made round a point are together equal to four right angles.

M 31 V.

[*A man's leap*]

If a man in taking a leap upon a firm spot leaps three braccia and recoils as he takes his spring a third of a braccio, what would he lack of his first leap?

And in like manner if it was increased by one third of a braccio how much would he have added to his leap?

M 55 r.

[*Pyramids*]

Multiply by itself the root of the number of this pyramid that you wish and detach it towards some angle.

If I wanted the fourth part of the height of the base of this pyramid which corresponds to the fourth part of the length of the pyramid I should say: — four times four are sixteen, and so the piece removed will be one sixteenth of the whole pyramid. And if you take away a part such as the half of the base which corresponds to the half of the length of this pyramid, you will say a half of a half is a quarter; therefore the part taken away will be a quarter of the whole pyramid, and if you multiply the three quarters of the base by the three quarters of the length of the pyramid this will make nine sixteenths of the whole pyramid.

This curved pyramid will find its end by finishing its circles. But if such a pyramid were to go thousands of miles to unite itself you would not be able to complete these circles; employ therefore the scale given.

M 86 V.

[*Curved lines and pyramids*]

If you cut above a section equidistant to the circle below making use of its centre *r*, and if you cut below a section equidistant to the circle above making use of its centre *a*, I wish to know if these two lines be drawn with the same curve at what distance they will join, or if they do not join where they will make their first approach and how distant they will ever be and how near to each other.

I wish as regards two given lines which are curved to find whether they are parallel or no, and if they are not parallel whether they are so arranged as to form a pyramid or no, and if they ought to form a pyramid at what fixed distance from the base their curved sides ought to join.

And for this you will act as follows: detach a part between the base and the side and let this part be as great of such part of the base as of the side, and the portion may be taken either from the part above or the part below; and if you take it off the part above make it so that the section may be equidistant to the circle below using its centre *r*, and if you remove this portion from below make the section equidistant to the line above using its centre *a*, and if you take away this portion below make the section equidistant to the line above using its centre *a*, and so continuing as the straight pyramid.

M 87 r.

[*Geometrical paradox*]

If the angle is the contact of two lines, as the lines are terminated in a point an infinite number of lines may commence at this point, and conversely an infinite number of lines may end together at this point; consequently the point may be common to the beginning and the end of innumerable lines.

And here it seems a strange matter that the triangle is terminated in a point with the angle opposite to the base, and from the extremities of the base one may divide the triangle into an infinite number of parts; and it seems here that as the point is the common end of all the said divisions the point as well as the triangle is divisible to infinity.

M 87 v.

The lines which form the circular parallels cannot be of the same curve because as they complete their circles they will have their contact or intersection in two places.

As regards the curved lines which have to make up the curved parallels, it is necessary that the part and the whole of the one and the part and the whole of the other should be together each of itself equidistant to a single centre.

M 89 r.

SPHERICAL ANGLES EQUAL TO RIGHT ANGLES

Every four angles made within the circle of all the space of the circle are equal to four right angles, whether the lines be curved and straight or all straight or all curved.

Every quantity of lines that intersect at the same point will form as many angles round this point as there are lines that proceed from it, and these angles joined together will be equal to four right angles. M 89 v.

[*With diagram*]

Pelacani[1] says that the longer arm of this balance will fall more rapidly than the shorter arm because in its descent it describes its quarter circle more directly than the shorter arm does; and that since the natural tendency of weights is to fall by a perpendicular line the more the circle bends the slower will the movement become.

The diagram *m n* controverts this argument in that the descent of

[1] According to M. Ravaisson-Mollien the reference is to Biagio Pelacani of Parma (born 1416), whom Tiraboschi calls *filosofo e matematico insigne*.

the weights does not proceed by circles, and yet the weight of *m* the longer arm falls.

When anything is farther away from its base it is less supported by it; being less supported it keeps more of its liberty, and since a free weight always descends, the extremity of the rod of the balance which is most distant from the point of support, since it is heavy, will descend of itself more rapidly than any other part. MS. 2038 Bib. Nat. 2 v.

[*Levers*]

In proportion as the extremity of the upper part of the balance approaches more nearly to the perpendicular line than the extremity of the lower part, so much longer and heavier will the lower arm be than the upper arm if the beam be of uniform thickness. MS. 2038 Bib. Nat. 3 r.

[*Suspended bodies*]

The suspended body which is of smooth roundness will fall in the line of its centre and will stop under the centre of the cord by which it is suspended.

The centre of the weight of any suspended body will stop in a perpendicular line beneath the centre of its support. MS. 2038 Bib. Nat. 3 v.

Gravity, force and material movement together with percussion are four accidental powers in which all the visible works of mortals have their being and their death.

Gravity is a certain accidental power which is created by movement and infused into one element which is either drawn or pushed by another, and this gravity possesses life in proportion as this element strives to return to its former state. B.M. 37 v.

The redness or yolk of the egg remains in the centre of the albumen without sinking on either side, and it is either lighter or heavier or the same weight as this albumen. If it is lighter it ought to rise above all the albumen and remain in contact with the shell of the egg; and if it is heavier it ought to sink down; and if it is of the same weight it ought to be capable of remaining at one of the ends just as well as in the centre or below it. B.M. 94 v.

The thing moved will never be swifter than its mover. B.M. 121 v.

The boundary of one thing is the beginning of another.

The boundaries of two bodies joined together are interchangeably the surface the one of the other, as water with air.

B.M. 132 r.

OF THE ELEMENTS

The bodies of the elements are united and in them there is neither gravity nor lightness. Gravity and lightness are produced in the mixture of the elements.

A point is that which has no centre.

A line is a length (extension) produced by the movement of a point, and its extremities are points.

A surface is an extension made by the transversal movement of a line, and its extremities are lines.

A body is a quantity formed by the lateral movement of a surface, and its boundaries are surfaces.

A point is that which has no centre, and from this it follows that it has neither breadth, length nor depth.

A point is that which has no centre, and therefore it is indivisible from any angle and nothing is less than it is.

A line is a length made by the movement of a point, wherefore it has neither breadth nor depth.

A body is a length and it has breadth with depth formed by the lateral movement of its surface.

B.M. 160 r.

[*Definitions*]

A point has no part; a line is the transit of a point; points are the boundaries of a line.

An instant has no time. Time is made by the movement of the instant, and instants are the boundaries of time.

An angle is the contact of two lines which do not proceed in the same direction.

A surface is the movement of a line, and lines are the boundaries of a surface.

A surface has no body; the boundaries of bodies are surfaces.

B.M. 176 r.

A pyramidal body is that of which all the lines that proceed from the angles of its base meet in a point.

And a body such as this may be clothed with an infinite number of angles and sides.

A wedge-shaped body is one in which the lines that issue forth from the angles of the base do not meet in one single point but in the two points which end the line; and this ought not to exceed or fall short.

B.M. 176 v.

An instant has no time, for time is formed by the movement of the instant and instants are the boundaries of time.

A point has no part.

A line is the transit of a point.

A line is made by the movement of a point.

Points are the boundaries of a line.

An angle is the contact of the extremities of two lines.

A surface is formed by the movement of a line moved sideways to the line of its direction.

B.M. 190 v.

[*Propositions*]

Every body is surrounded by an extreme surface.

Every surface is full of infinite points.

Every point makes a ray.

The ray is made up of infinite separating lines.

In each point of the length of any line whatever, there intersect lines proceeding from the points of the surfaces of the bodies and [these] form pyramids.

Each line occupies the whole of the point from which it starts.

At the extremity of each pyramid there intersect lines proceeding from the whole and from the parts of the bodies, so that from this extremity one may see the whole and the parts.

The air that is between bodies is full of the intersections formed by the radiating images of these bodies.

The images of the figures and colours of each body are transferred from the one to the other by a pyramid.

Each body fills the surrounding air by means of these rays of its infinite images.

The image of each point is in the whole and in the part of the line caused by this point.

Each point of the one object is by analogy capable of being the whole base of the other.

Each body becomes the base of innumerable and infinite pyramids.

That pyramid which is produced within more equal angles, will give a truer image of the body from whence it is produced.

One and the same base serves as the cause of innumerable and infinite pyramids turned in various directions and of various degrees of length.

The point of each pyramid has in itself the whole image of its base.

The centre line of the pyramid is full of the infinite points of other pyramids.

One pyramid passes through the other without confusion.

The quality of the base is in every part of the length of the pyramid.

That point of the pyramid which includes within itself all those that start upon the same angles, will be less indicative of the body from whence it proceeds than any other that is shut up within it.

The pyramid with the most slender point will reveal less the true form and quality of the body from whence it starts.

That pyramid will be most slender which has the angles of its base most unlike the one to the other.

That pyramid which is shortest will transform in greatest variety the similar and equal parts of its base.

Upon the same quality of angles will start pyramids of infinite varieties of length.

The pyramid of thickest point, more than any other will dye the spot on which it strikes with the colour of the body from which it is derived.

B.M. 232 r.

OF THE NATURE OF GRAVITY

Gravity is a fortuitous quality which accrues to bodies when they are removed from their natural place.

OF THE NATURE OF LEVITY

Levity is allied with gravity as unequal weights are joined in the scales, or light liquids are placed beneath liquids or solids which are heavier than they . . .

B.M. 264 r.

Take from one of five regular bodies a like body and so that what is left may be of the same shape.

I wish to take a given pentagon from another pentagon and so that

the remainder may stay in the form of a pentagon, and they may be bodies and not surfaces.

Reduce the given pentagon into its cube, and proceed thus with the greater pentagon from which you have to extract the lesser; then by the past rules take the lesser cube from the greater cube, and then remake the pentagon from the remainder of this greater cube, which by the aforesaid rules has remained cubed.

That which is here said of the cube is understood of all bodies which touch the sphere with their angles, for what is made in the sphere may be made in the cube.

Forster I 5 r.

All bodies have three dimensions, that is breadth, thickness and length.

The changes and manipulations of bodies are six, namely shortening and lengthening, becoming thicker and thinner, being enlarged and compressed.

The surface has breadth and length and is uniformly devoid of thickness.

The board is a flat body and has breadth, length and uniform thickness.

Therefore when the board is of uniform thickness and its surface of uniform quality we may use the table in all its manipulations and divisions in the same manner and with the same rules as we use the above mentioned surfaces.

Forster I 12 v.

[*Diagram*]

The regular bodies are five and the number of those participating between regular and irregular is infinite: seeing that each angle when cut uncovers the base of a pyramid with as many sides as were the sides of this pyramid, and there remain as many bodily angles as there are sides.

These angles may be bisected anew and so you may proceed an infinite number of times because a continuing quantity may be infinitely divided.

And the irregular bodies are also infinite through the same rule aforesaid.

Forster I 15 r.

I will reduce to the form of a cube every rectangular body of equidistant sides. —

And first there will be a cylinder.

To get the square of a rectangular board that is longer than it is wide according to a given breadth: ask yourself by how much its size varies.

This may be done by the fifth of this, that is that I shall make of the width or length of this board the cylinder of length equal to the said width or length of the board, and then . . .

Forster I 31 r.

Geometry extends to the transmutations of metallic bodies, which are of substance adapted to expansion and contraction according to the necessities of their observers.

All the diminutions of cylinders higher than the cube keep the name of cylinder. All the diminutions of the cylinder that are lower than the cube are named boards.

The cube, a body of six equal sides contained by twelve equal lines and eight angles of three rectangular sides and twenty-four right angles; which body among us is called a die.

When you wish to treat of pyramids together as regards their increase or diminution, and you treat of cylinders, cubes or boards which should be of the same height and breadth as these pyramids, then the third of these bodies will remain in the said pyramid; and this you will put concisely.

Forster I 40 v.

METHODS OF MEASURING A HEIGHT

Let *c f* be the tower you wish to measure; go as far away from it as you think desirable and take the range of it, as is shown in *c b a*, which may be the length of an arm and half as high, and work it so that the tower occupies the space *b a*; then turn the line *b a* along the level of the ground, and it occupies as great a space of ground as it occupied in height, and in the space of ground which it has occupied you will find the true altitude of the tower.

Forster I 48 v.

[*Diagrams*]

If a line falls perpendicularly upon another line it ends between two right angles.

If a straight line falls upon another straight line and passes to the intersection this intersection will stand in the middle of four right angles.

If the two straight lines which intersect together between four right

angles shall have their four extremities equidistant to this intersection, it is necessary that these ends be also equidistant from one another.

Forster II 3 v.

If two circles intersect in such a way that the line of the circumference of the one is drawn over the centre of the other as the other is of it, these circles are equal, and the straight lines which pass from the two points of intersection and from the centre to the other intersect together within four right angles, and the circle made upon the two centres will remain divided in four equal parts by such said intersection, and there will be made a perfect square.

Forster II 4 r.

If two three or four equal things are placed upon a thing which is equal to them all, the part of the greater which protrudes will be equal to the sum of the protruding parts of all the lesser ones; and the example is the figure below.

Forster II 4 v.

ACTUAL PROOF OF THE SQUARE

If four circles be so placed as to have their centres situated upon the line of a single circle, in such a way that the line of the circumference of each is made over the centres of each, undoubtedly these will be equal, and the circle where such intersection is made remains divided in four equal parts, and it is in the proportion of a half to each of the four circles, and within this circle will be formed the square with equal angles and sides.

Forster II 5 v.

Every continuous quantity is divisible to infinity.

Forster II 53 v.

Gravity, force and accidental movement together with percussion, are the four accidental powers with which all the visible works of mortals have their existence and their end.

GRAVITY

Gravity is accidental power, which is created by movement and infused in bodies standing out of their natural position.

HEAVY AND LIGHT

Gravity and lightness are equal powers created by the one element transferred into the other; in every function they are so alike that for a

single power which may be named they have merely variation in the bodies in which they are infused, and in the movement of their creation and deprivation.

That body is said to be heavy which being free directs its movement to the centre of the world by the shortest way.

That body is said to be light which being free flees from this centre of the world; and each is of equal power.

Forster II 116 v.

Gravity, force, together with percussion, are not only interchangeably to be called mother and children the one of the other and all sisters together, because they may be produced by movement, but also as producers and children of this movement; because without these within us movement cannot create, nor can such powers be revealed without movement.

Forster II 117 r.

The accidental centre of the gravity that descends freely will always be concentric with the central line of its movement, even though this gravity should revolve in its descent.

Forster II 125 v.

[*Sketch*]

a n forms the groove in the bank a quarter of a braccio on the inside, by means of the grooves or teeth of iron, and these teeth rub against the bases of the bank, and afterwards one seizes the handles of the rake, and the soil that has collected upon it is placed in the box.

Forster III 18 r.

[*Diagram*]

That which is called centre is an indivisible part, and may more readily be considered as round than of any other shape; therefore the first part that surrounds it round is divisible whatever it may be; if it be in the square beaten into a circle it enlarges.

Forster III 26 v.

[*Sketches*]

The angle is terminated in the point; in the point intersect the images of bodies.

Forster III 29 v.

[*Sketch*]

WORM OF SCREW

The line *b d* ought to show how much this turns and similarly how much the circle of the line *a o* turns, and take the number that is found

between the one number and the other; and upon this make your calculation as is shown here below.

[*Sketch*]

m n is the line that finds itself between *b d* and *a o*, which you will cause to take the direction as shown here below.

[*Sketch*]

c r is the extent to which this line is slanting, that is the extent to which the worm of the screw above turns over and drops. Forster III 81 v.

[*Sketch*]

Multiply the line *a o* by the line *o p*, and that which results multiply with it that number of the parts of the half-diameter of the screw which finds itself upon the length of the lever; and that which results apportion it. Forster III 82 r.

And if you should only know the weight of the thing that you wish to raise with the tackle and did not know how great weight or force was necessary in order to raise this weight, divide the number of the pounds of your weight by the number of the wheels that there are in the tackle, and that which comes out will be the uncertain weight which will resist the certain with equal forces. Forster III 82 v.

If you wish with certainty to understand well the function and the force of the tackle, it is necessary for you to know the weight of the thing that moves or the weight of the thing moved; and if you would know that of the thing that moves multiply it by the number of the wheels of the tackle, and the total that results will be the complete weight which will be able to be moved by the moving thing. Forster III 83 r.

Such proportion will the weight have which is suspended by means of the lever through the cord of the windlass to the force that the mover exerts for its suspension, as has the half of the diameter of the windlass to the space that is found upon the lever, between the hand of its mover and the centre of the thickness of the said windlass. Forster III 83 v.

[*Sketch*]

If you multiply the number of the pounds that your body weighs by the number of the wheels that are situated in the tackle you will find

that the number of the total that results will be the complete quantity of pounds that it is possible to raise with your weight. Forster III 84 r.

That body of which the parts that are enclosed between the surface and the centre are equal in substance, weight and size, if it be suspended transversely by its opposite extremities will give an equal part of its weight to its supports.

That wheel of which the centre of the axis is the centre of its circle, will in all circumstances perform its functions in perfect balance; and equal bodies suspended from the opposite extremities of its circle will stand in equal counterpoise the one to the other. Forster III 84 v.

[*Sketch — tackle*]

It can be so made that although the counterpoises are different in weight the one to the other in equal arms of balances, they stand at equal resistance the one to the other: see in the instrument represented in the equal arms of the upper balances, sixteen [pounds] weight below stands in resistance to eight. Forster III 85 r.

In proportion as the number of the wheels is greater so will the fall of the counterpoise be greater than the rise of the greater weight.

In proportion as the number of the wheels is greater so will the number of the arms of the cord collected by the windlass be greater than that of the weight that is raised. Forster III 85 v.

The pulling of the tackle requires force, weight, time and movement.

OF THE MOVEMENT OF THE CORDS

As many as may be the number of the wheels of the tackle so much will the cord be swifter in its first movement than in its last.

OF THE WEIGHT

In proportion to the number of the wheels so much will the weight sustained be greater than that which supports it. Forster III 86 r.

[*Sketch. 'Cord of the windlass.' 'Multiply that weight by the number of the wheels.'*]

If you wish to ascertain how much cord a windlass will collect after it has passed through the whole or as few as two [turns] of a tackle of four wheels, know that for every braccio that the weight is raised, the windlass will collect four [braccia] by the four wheels of the tackle; and if the wheels were twenty, for every braccio that the weight was raised the windlass would need two braccia of cord.

In the raising of the weight the windlass would need as many times more braccia of cord than the weight would raise, according to the number of the wheels which are collected in the tackle.

Forster III 86 v.

If the wheels are two and you wish to raise the weight one braccio the windlass collects two braccia; the proof is this: let us say *n m* is one braccio, and so *n f* may be another; let us say that I wish to raise the weight *m* one braccio: it is evident that the cord *n m f* which is two braccia will be no more in its position and the windlass will gather up as much again.

In proportion to the number of the wheels that move in the tackles by so much will the cord of the first movement be swifter than that of the last.

Forster III 87 r.

DEFINITION OF THE NATURE OF THE LINE

The line has not in itself any matter or substance but may more readily be called an incorporeal thing than a substance, and being of such condition it does not occupy space. Therefore the intersections of infinite lines may be conceived of as made at a point which has no dimensions, and as to thickness, if such a term can be employed, is equal to the thickness of one single line.

HOW WE CONCLUDE THAT THE SURFACE TERMINATES IN A POINT

An angular surface becomes reduced to a point when it reaches its angle; or if the sides of this angle are produced in a straight line, then beyond this angle there is formed another surface, less or equal or greater than the first.

Windsor MSS. R 47

Every point is the head of an infinite number of lines, which combine to form a base, and suddenly from the said base by the same lines converge to a pyramid showing both its colour and its form.

No sooner is the form created or compounded than suddenly of itself it produces infinite angles and lines, which lines spreading themselves in intersection through the air give rise to an infinite number of angles opposite to one another. With each of these opposite angles, given a base, will be formed a triangle alike in form and proportion to the greater angle; and if the base goes twice into each of the two lines of the pyramid it will be the same with the lesser triangle.

Windsor MSS. R 62

Archimedes has given the square of a polygonal figure, but not of the circle. Therefore Archimedes never found the square of any figure with curved sives; but I have obtained the square of the circle minus the smallest possible portion that the intellect can conceive, that is, the smallest point visible.

Windsor: Drawings 12280 v.

If into a vessel that is filled with wine as much water is made to enter as equals the amount of the wine and water which runs out of it, the said vessel can never be altogether deprived of wine. This follows from the fact that the wine being a continuous quantity is divisible to infinity, and therefore if in a certain space of time a particular quantity has poured away, in another equal space of time half the quantity will have poured away, and in yet another a fourth of the quantity; and what is left is constantly being replenished with water; and thus always during each successive space of time the half of what remains will be poured out. Consequently, as it is capable of being divided to infinity, the continuous quantity of the aforesaid wine will be divided during an infinite number of spaces of time; and because the infinite has no end in time there will be no end to the number of occasions on which the wine is divided.

Leic. 26 v.

Instrumental or mechanical science is the noblest and above all others the most useful, seeing that by means of it all animated bodies which have movement perform all their actions; and the origin of these movements is at the centre of their gravity, which is placed in the middle with unequal weights at the sides of it, and it has scarcity or abundance of muscles, and also the action of a lever and counter-lever.

Sul Volo 3 r.